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Reconnaissance, Scout and Targeting Vehicle (RST-V) Interim Report

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The main focus of this study was to explore vehicle layouts, powertrain configurations, and suspension options for increased mobility and performance in an 8000 lb. GVW wheeled vehicle subject to an the environmental requirements of mission, transportation and payload.

The government supplied performance requirements for the RST-V in its intended operational environment were reviewed. Mission requirements such as V-22 (Medium Lift Replacement (MLR)) transportability and the availability of on-board power for advanced target acquisition equipment were used to evaluate specifications for overall vehicle and detailed subsystem specifications and to recommend modifications to the specification. A detailed study of mission specific payload weight and volumes was conducted to better evaluate cargo volume, form factor, and total mass requirements. The maximum envelope for an internally transportable vehicle was determined using the functional mockup of the V-22 in Patuxent River.

This included extensive testing, data gathering and simulation to provide a comparison between traction and high speed mobility over rough terrain for four, six and eight wheeled configurations.

14. SUBJECT TERMS

RST-V	V-22	Medium Lift Replacement
Vehicle Layouts	Powertrain Configurations	Suspension Options
Mission	Transportation	Payload
Internally Transportable Vehicle		Future Scout Vehicle

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Reconnaissance, Scout, and Targeting Vehicle (RST-V) Interim Report

Prepared by AeroVironment

for the

Carderock Division

of the

USMC Naval Surface Warfare Center

January 29,1997

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1. Executive Summary

AeroVironment Inc. and Rod Millen Special Vehicles Inc. jointly performed a design study for an advanced Reconnaissance Scout and Targeting Vehicle (RST-V). The main focus of this study was to explore vehicle layouts, powertrain configurations, and suspension options for increased mobility and performance in an 8000 lb. GVW wheeled vehicle subject to the environmental requirements of mission, transportation and payload.

The government-supplied performance requirements for the RST-V in its intended operational environment were reviewed. Mission requirements such as V-22 (Medium Lift Replacement (MLR)) transportability and the availability of on-board power for advanced target acquisition equipment were used to evaluate specifications for overall vehicle and detailed subsystem specifications and to recommend modifications to the specification. A detailed study of mission specific payload weight and volumes was conducted to better evaluate cargo volume, form factor, and total mass requirements. The maximum envelope for an internally transportable vehicle was determined using the functional mockup of the V-22 in Patuxet River.

Using the above generated constraints, the study included an analysis of required vehicle performance under expected mission scenarios. This included extensive testing, data gathering and simulation to provide a comparison between the traction and high-speed mobility over rough terrain for four, six and eight wheeled configurations including options for articulated vehicles or powered trailers. Using the data gathered in the testing program, a parametric analysis of potential design schemes was performed to arrive at the optimal driveline configuration. In addition, a search was conducted to identify existing commercial electrical and vehicle components which might be of the appropriate level of technology to be included in a military vehicle. Every attempt was made to make a notional RST-V platform potentially logistically compatible with future Light Strike Vehicle platforms and the lightweight Future Scout Vehicle (FSV).

2. Goals of RST-V Study

The goal of the first phase of the RST-V program was to evaluate multiple concepts for a high performance wheeled combat vehicle for future Marine Corp. and Special Operations missions, and to recommend a configuration that best fulfills the desired missions for this platform. The initial phase included examination of current military mission requirements and development of a set of key vehicle parameters and determine the suitability of proposed layouts and of a hybrid drive approach. Critical issues which drive the design for the final vehicle include performance in both acceleration and gradeability, speed over rough terrain, mobility in low speed, low traction situations, sea water and dust exposure, field maintainability, and internal helo-transportability as well as cargo requirements for specific mission scenarios and minimum payload capability (3000 lbs.).

An important design issue to be considered was the potential benefit of a hybrid drive train vs. its added complexities and failure modes. The hybrid vehicle advantages demonstrated in the JTEV program include enhanced range due to higher overall efficiency, reduced thermal, visual and acoustic signatures, i.e. "silent running", and availability of substantial auxiliary electric power for mission payloads. The RST-V study was designed to further evaluate the effects of powertrain choice on system weight and the impact on payload, acceleration, gradeability, and tractive effort in various soil conditions to determine whether a hybrid drive system will help or hinder the mission utility of this class of vehicle.

3. Technical Approach

3.1. Review/generate requirements (Preliminary Work)

The first part of the RST-V contract was to perform studies to help better define the requirements for such a platform. These studies included a definition of the maximum envelope for the vehicle (V-22 Fit Check Study), a study of the weight and volume required for the various mission cargoes (Weight and Volume Study), a review and evaluation of the preliminary Joint Operational Requirements Document (JORD) (Requirements Review), an examination of all commercially available vehicles to determine if any would meet the JORD (Commercial Vehicle Survey), and an evaluation of the performance requirements necessary to meet the expected missions (Mission Profile Analysis). The results of these studies were provided to Carderock NSWC. A summary of these reports is in Section 4.

3.2. Generate Multiple concepts

The next step in the program was to generate a wide range of conceptual vehicle layouts, subject to the performance requirements and constraints determined in the first part of the program. From this large set, the key differentiating features between each of the vehicle configurations were determined, and comparison studies designed to evaluate the advantages and disadvantages of each approach. Overall vehicle configuration issues such as number of driving wheels, overall tractive effort, steering and suspension schemes and cargo volume were examined to determine the optimal layout given the constraints of weight and physical envelope of the MLR cargo bay. A description of the concepts under consideration is in section 5.

3.3. Evaluate Suspension, Wheels, and Steering

An analysis was conducted to find vehicle configurations that would meet the desired physical operating objectives. Steering systems were evaluated on their ability to meet the turning radius objectives while providing compatibility with long travel suspensions. The NATO Reference Mobility Model II was used to predict the one-pass Vehicle Cone Index through fine-grained soils of many combinations of tire number, width and diameter to find suitable candidates that meet the VCI_1 objective of 15. The swept volume of the tire combinations were calculated to find the configuration which maximizes available cargo space while meeting all of the performance criteria. Various suspension systems were qualitatively evaluated based on their compatibility with long travel suspension, adjustability, high speed performance, package volume, and ground clearance. The analyses are described in sections 6.1 through 6.5.

3.4. Evaluate Possible Configurations and Sizing Layout

A preliminary packaging study was performed to visualize the crew spaces, cargo area, tire volumes and powertrain requirements. The goals were to gain a perceptual understanding of the space claims necessary for tires, personnel, and powertrain using current technology components. Alternate configurations show the suitability in the mission profiles of litter, weapons, personnel, and sensor carriers. This was not to develop point designs, but to demonstrate spatial feasibility for the various configurations. See figures in section 5.

3.5. Design a "Mobility Filter" for Simulator

A "mobility filter" was designed as a front end for the AV vehicle simulator CarSIM. It was designed to calculate wheel velocity and torque as a function of soil type, surface roughness rms, vehicle velocity, suspension travel. The required data to generate these relations was determined, and a test plan developed to collect the required empirical data. See section 6.7 for a detailed description of the generation.

3.6. Test the Vehicle and Generate Data

JTEV and HTMMP were both fitted with instruments to measure and record vehicle speed, wheel torque, wheel speed, suspension position, throttle position, and in the case of JTEV, commanded drive power and drive inverter voltage and current. Suitable terrain was identified for performing each test in the test plan and the surface of each was surveyed. In an area of silty, clayey sand (SM-SC soil classification), three different rms - low, medium and high - courses were found and elevation was mapped for each foot of the 600 ft courses. Soil samples were taken each test day to ensure that the results could be correlated correctly. Soil samples were also taken for the loose sand and hard packed sand courses. Different suspension travels were tested by running JTEV at 18" of wheel travel, and HTMMP at both 15" and 10" of wheel travel. See sections 6.7.2 through 6.7.5.

See Appendix A for the test plan and Appendix B for an example of raw data.

3.7. Reduce and Analyze Data

Performance evaluation criteria were used to rank the relative merits of the various designs. Several viable configurations were then chosen, examined and presented in much closer detail including some layout design work. Failure modes and effects of failures for each of the configurations were assessed, and a final recommendation made. See sections 7, 8, 9, and 10.

4. Preliminary work

4.1. V-22 Fit Check

The physical size and shape of the MLR cargo bay offers a significant design challenge. The vehicle may not exceed the 250" length of the MLR cargo bay and must be able to drive through an entrance which is 68" wide and 66" high. The 13,000 lb. lift capability of the helicopter which is reduced to 7500 lb. at 4000 ft indicates that, for maximum mission flexibility, the vehicle should be as light as possible while still being capable of carrying 3000lb payload at sea level. This means that the frontal area and shape of the RST-V will have to be virtually identical to the HTMMP and JTEV, yet the desired payload is tripled. This will require a longer vehicle to provide sufficient payload area and crew area.

In order to determine the maximum envelope available for the RST-V, staff from RMSV used the V-22, Aircraft Number two (A/C-2) airframe, located at NAS, Patuxent River, to verify both the internal fit of the Joint Tactical Electric Vehicle (JTEV), and a cardboard and foam 'mockup' of the proposed RST-V maximum dimensions. A/C-2 was chosen for this task because is had been modified to match the current engineering, manufacturing development (EMD) version of the aircraft.

The JTEV was shown to fit internal to the V-22 in both a backward and forward configuration at both low and high ride heights with and without the 50 caliber, M-2 machine gun mounted.

A notional RSTA-V model constructed of foam board, wood, and PVC piping was used to determine the maximum vehicle dimensions. The model was able to be positioned to yield 10, 12, 15, and 18 inches of ground clearance and the axles were adjustable to provide 65 to 68 inch track width in one inch increments. The model was built in a three axle configuration with the rear two axles located at 119 and 162 inches aft of the front axle. The model of the vehicle body contained one side profile located in the center of the wheel track and three front profiles located along the length of the vehicle.

The model was rolled in and out of the V-22 in varying configurations to determine the maximum vehicle envelope. Modifications to the model were made where interference was encountered. CAD models were then used to illustrate approximate breakover clearance and V-22 interference with the ramp set at the maximum angle of 18.5 degrees. With simulated wheel travel included in the model, the RSTA-V was shown to be able to enter the aircraft driven backward at ride heights of 12, 15, and 18 inches. The model showed the vehicle able to enter the aircraft driven forward at 15 and 18 inch ride heights without interference.

Several issues which still need to be addressed in the compatibility of the RSTA-V and the V-22 include: tiedown criteria and location for a 8000 pound vehicle; matching the RSTA-V center of gravity with the aircraft cargo center of gravity envelope; crew seating requirements; electromagnetic interference from a hybrid electric vehicle; and foreign object damage of the V-22.

It was found that the volume constraints will be the driving parameter for the cargo area, not the overall weight unless the payload consists entirely of extremely heavy objects such as ammunition and water. The distance between the wheels and the desired approach and departure angles will make a four wheeled vehicle impractical. A longer four wheeled vehicle would be extremely prone to high centering over obstacles such as rocks and fallen logs. Therefore a six or eight wheeled vehicle will be the more likely choice.

Refer to document "V-22 Fit Check Study" for details.

4.2. Commercial Vehicle Study

A survey of commercially available vehicles designed for part-time off-highway use was conducted with reference to the specific attributes desirable in the RST-V. The purpose of the survey was to determine if any vehicle (or vehicles) meets, in full or in part, the general requirements of the RST-V program, and to then estimate what changes (deletions, modifications, replacements and additions) would be necessary to fully satisfy the RST-V Joint Operational Requirements Document (JORD).

The criteria that were used to compare the vehicles included: Width; Height; Ground Clearance; Diesel Availability; Gross Vehicle Weight Required (GVWR); Payload (weight); Cargo Capacity (volume); Tow Rating; Turning circle; and Range.

Two vehicles, the Toyota Tacoma and the GMC Sierra, were selected for further considerations as they achieved the highest average score and the best average scores for their GVWR (Average Score/GVWR). However, both of these would require radical and expensive modifications, and then would only marginally achieve the requirements. The exercise of considering these vehicles and the required changes to meet the LSV capabilities demonstrated several important points. Some of these are listed below:

1. Across the board, commercial pick-up and utility vehicles are not designed to meet the payload fraction and long form-factor required of the RST-V.

2. In a very fundamental sense, commercial vehicles are exactly that; commercial. They are designed to be most desirable to consumers at a competitive price. Off-road mobility is thoroughly compromised for low cost, on-road handling and high speed stability. The average consumer does not need the capabilities of the RST-V, and they are therefore not present in the commercially available vehicles.

3. Heavily adapted commercial vehicles will be relatively costly and meet only a fraction of the desired RST-V capabilities. As further adaptations are made, the diminishing returns become obvious. Vehicles fully adapted to meet all of the JORD will have little, if any, original equipment left.

4. The most economical way to meet the combined transportability, mobility, survivability, military compatibility, and reliability requirements is to focus on the design and development of a purpose-built vehicle.

Refer to document "Commercial Vehicle Study" for details.

4.3. Requirements Review

An analysis of the probable missions for the Reconnaissance Surveillance Target Acquisition Vehicle (RSTA-V) was conducted with reference to the Program Objectives, as stated by the NSWC-CD, and the specific vehicle capabilities spelled out in the RSTA-V System/Segment Specification (SSS).

The primary Program Objectives were determined to be: V-22 Compatibility; Multiple Vehicle Configuration; and Survivability. The first step was to determine whether the mission to be scrutinized is consistent with the Primary Objectives of this vehicle. The

second step was to determine whether the mission would require capabilities outside of those set forth for the vehicle in the SSS.

Refer to document "Requirements Review" for details.

4.4. Loaded Item Weight and Volume

Based on projected mission requirements for RSTV a substantial payload capacity will be needed. It is estimated that a 3000 pound payload would satisfy the envisioned SOCOM and USMC mission scenarios. This payload represents a significant design feature in a narrow wheel base vehicle intended to be carried inside a V-22 Osprey medium lift replacement aircraft.

To validate future vehicle concepts and designs against payload requirements, applicable mission equipment and supplies were measured and weighed. A representative list of military equipment was produced and agreed upon. The items were found to be available at MCB Camp Pendleton. RMSV personnel weighed, measured and photographed the equipment and supplies. Based on the recorded data, Table 4.4 was developed to detail the information. (Further data is included in the appendices.) The equipment and supplies were categorized as follows:

1. Crew and Personal Equipment
2. Main Weapon and Ammunition
3. Water, Rations, and Petroleum Products
4. Communications Equipment
5. Vehicle on Board Basic Equipment.

The total weight of the equipment measured was 1406 pounds with a measured cumulative volume of approximately 32 cubic feet. It is evident given this mixture of typical equipment, the vehicle will be constrained in volume before reaching a payload weight of 3000 pounds. This is further exacerbated in the fact that in simply adding each component's volume to reach a total implies an unrealistic packing efficiency. The data recorded can be utilized upon further definition of mission requirements and objectives.

RSTA-V WEIGHT AND VOLUME STUDY										
VEHICLE, BASIC LOAD LIST										
ALL WEIGHTS ARE NATO AVERAGES										
		ITEM	NUMBER	TOTAL	LENGTH	HEIGHT	WIDTH	VOLUME	TOTAL	
		WEIGHT		WEIGHT				PER ITEM	VOLUME	
1.	CREW AND PERSONAL EQUIPMENT									
a	NATO average crewman	176	2	352	N/A	N/A	N/A	N/A	N/A	
b	Personal weapon rifle	8	2	16	39.25	9	2.5	883.1 cu in	1766.3 cu in	
c	Weapon cleaning kit	0.8	2	1.6	N/A	N/A	N/A	N/A	N/A	
d	Ammunition (5x30 round mag's)	5	2	10	7.25	0.875	2.5	15.9 cu in	31.7 cu in	
e	Ruck sack with standard field gear	65	2	130	26	14	24	8736.0 cu in	17472.0 cu in	
				509.6				9635.0 cu in	19270.0 cu in	
2.	MAIN MOUNT WEAPON AND AMMUNITION									
a	Standard Browning .50 cal MG	85	1	85	65.5	9	7.5	4421.3 cu in	4421.3 cu in	
b	Night sight	11	1	11	15	7.25	6.5	706.9 cu in	706.9 cu in	
c	Spare barrel w/case	24	1	24	45	2.25	2.25	227.8 cu in	227.8 cu in	
d	Main weapon cleaning kit	3	1	3	N/A	N/A	N/A	N/A	N/A	
e	Ammunition (100 rd cans)	37	5	185	13.5	9	7.75	941.6 cu in	4708.1 cu in	
f	Vehicle soft mount	70	1	70	5	1	3.25	16.3 cu in	16.3 cu in	
			1		5	1	3.25	16.3 cu in	16.3 cu in	
			1		15.5	2.75	6.75	287.7 cu in	287.7 cu in	
				378				6617.8 cu in	10384.3 cu in	
3.	WATER, RATIONS, PETROLEUM PRODUCTS									
a	Combat ration 1 MRE	1	6	6	8.5	2	4.75	80.8 cu in	484.5 cu in	
b	Hexamine stove	0.5	2	1	4.75	1.25	3.75	22.3 cu in	44.5 cu in	
			1		3.75	0.75	2.5	7.0 cu in	7.0 cu in	
c	Water 5 gallons	35	1	35	13.75	19	7	1828.8 cu in	1828.8 cu in	
d	Fuel 1 gallon	21	6.5	136.5	13.75	18.25	6.5	1631.1 cu in	10602.1 cu in	
e	Oils motor 1 quart	2.75	4	11	4	9	2.5	90.0 cu in	360.0 cu in	
f	other lubricants 1 quart	2.75	4	11	4	9	2.5	90.0 cu in	360.0 cu in	
				200.5				3749.9 cu in	13686.9 cu in	
4.	COMMUNICATIONS EQUIPMENT									
a	VHF radio (Vehicle mount complete)	75.5	1	75.5	11	3.5	10.25	394.6 cu in	394.6 cu in	radio
			1		11	3.5	10.25	394.6 cu in	394.6 cu in	radio
			1		15.5	7.75	14.75	1771.8 cu in	1771.8 cu in	radio mount
			1		16.75	5	13.5	1130.6 cu in	1130.6 cu in	radio mount bracke
			1		11.25	3.75	5.75	242.6 cu in	242.6 cu in	amplifier
b	Vehicle Communication and intercom box 2/ca	16.5	1	16.5	6	3.75	4	90.0 cu in	90.0 cu in	
c	Crew helmets compatible w/above	3.75	2	7.5	10	9	8	720.0 cu in	1440.0 cu in	
				99.5				4744.3 cu in	5464.3 cu in	
5.	VEHICLE ON BOARD BASIC EQUIPMENT (OSE)									
a	Spare tire/wheel combination	65	1	65	36	12.5	16.5	7425.0 cu in	7425.0 cu in	
b	Jacking device	33	1	33	18	4.25	4.5	344.3 cu in	344.3 cu in	jack
			1		19	2.5	13	617.5 cu in	617.5 cu in	tools
c	Tow strap	4	1	4	3.5	1	1.75	6.1 cu in	6.1 cu in	
d	Shovel	3	1	3	47	2.5	18	2115.0 cu in	2115.0 cu in	
e	Axe	5.5	1	5.5	36	8	2.5	720.0 cu in	720.0 cu in	
f	Vehicle tools w/bag	25	1	25	18	4	4	288.0 cu in	288.0 cu in	
g	Spare parts pack	25	1	25	36	12	12	5184.0 cu in	5184.0 cu in	
h	First extinguisher and mount	6.5	1	6.5	5.5	5	16.25	446.9 cu in	446.9 cu in	
i	First aid kit	1.5	1	1.5	11	7.5	10.75	886.9 cu in	886.9 cu in	
j	Camouflage net w/support system	50	1	50	45	8	25	9000.0 cu in	9000.0 cu in	net
			1		49	12	12	7056.0 cu in	7056.0 cu in	supports
				218.5				34089.6 cu in	34089.6 cu in	Total per category
				1406.1				31803.0 cu in	55861.5 cu in	Totals

Table 4.4: Loaded Items

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4.5. Mission Profile Analysis

The Mission Profile Analysis study was intended to assess the RSTV program objectives against mission requirements. The purpose of the mission profiles is to ensure that mission requirements are addressed adequately in the objectives. The primary program objectives were delineated as follows:

1. V-22 compatible
2. Multiple vehicle configurations
3. Survivable

V-22 compatibility includes vehicular dimensions suitable for internal aircraft carriage. The vehicle weight is limited by the lift capacity of the aircraft at 8000 pound GVW. Ingress, egress and weapons deployment are also included as part of the aircraft compatibility objective. These aircraft operating factors impact the vehicle design, and the mission profile analysis would show the combat effectiveness of the vehicle designed to account for the described parameters.

A common chassis and drive train with multiple vehicle configurations would prove to be cost effective and provide operational flexibility. The configurations recommended in the program objective are weapons carrier, sensor platform, litter carrier and personnel transport. The sensor platform has become primary among these given the emphasis on reconnaissance and surveillance.

Survivability criteria include mobility, acquisition avoidance/signature reduction and fire power. Mobility is related to performance and can be attained through application of suspension technology. Reduced signature as a means of passive defense points toward vehicular treatments and electric drive. This combined with extensive range, long duration reconnaissance missions and sensor power requirements further push the vehicle design toward hybrid electric drive.

The program objectives are evaluated against the mission components to provide a profile. Foremost is the mission plan/task objective as mitigated by vehicle configuration, and natural and induced environments. This method of validating the program objectives will prove useful and effective as detailed mission requirements are finalized by the operating forces.

5. Conceptual Vehicles

5.1. Conventional Drive

A conventional Diesel engine driving through a conventional mechanical drivetrain was analyzed as a baseline starting point. This is best suited to the 4x4 version as it is the most space efficient drivetrain in the most space restricted vehicle. The primary disadvantage is the lack of onboard power and silent reserve power capability.

5.2. Series Hybrid

This layout uses a Diesel engine to drive an alternator to power a common electrical bus. The wheels are driven by electric motors that pull power from the bus as required. The engine is sized to deliver the average power required by the vehicle. A battery pack connected to the bus acts as a energy buffer and provides reserve power for periods of high power demand and stores the recovered energy available from regenerative braking. The primary advantages are higher overall operating efficiencies due to the smaller engine size required to supply less than peak power and packaging flexibility since power delivery is not through shafts. Additional advantages are three redundant drives are available, motors can be sized to run at high speeds which reduces operating currents, the highest flexibility for traction control systems is provided. The disadvantages are that the redundant gearboxes and motors are not weight efficient and an additional drive mechanism would be required to provide full mechanical jump start capability.

5.3. Series/Parallel Hybrid

Utilizing a series hybrid layout with the addition of a mechanical drive to one of the axles would provide the highest redundancy of all of the systems as it would allow full mechanical drive and electric drive. It would also provide for a mechanical jump start capability. The disadvantages are increased complexity and weight for the additional mechanical drive and the inability to use common gearbox components on all of the axles.

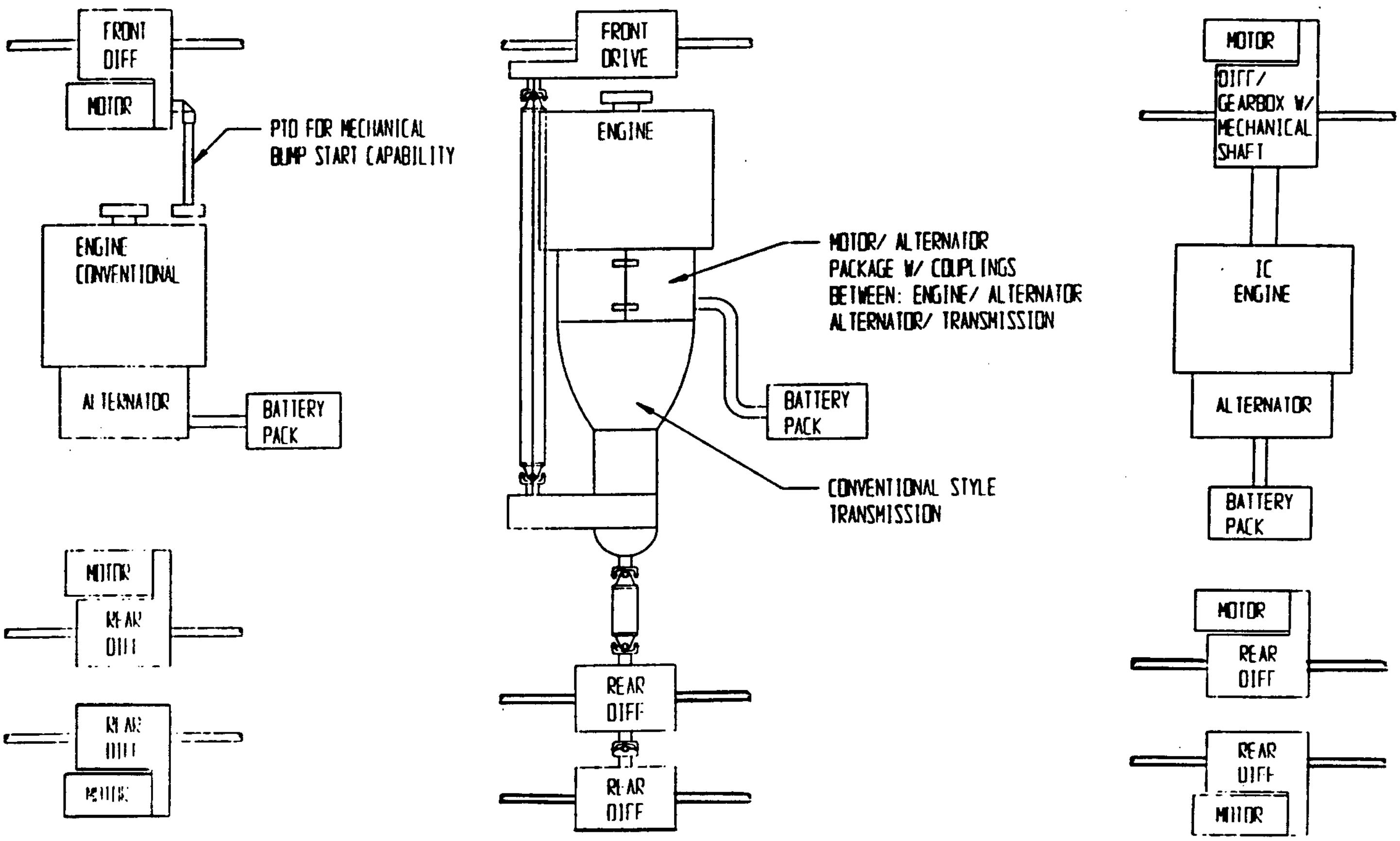
5.4. 4x4 and 6x6 Configurations

The 4x4 version uses a full mechanical drive. It has the least cargo volume available as it cannot grow in wheelbase and still meet the breakover angle and turn radius requirements and it cannot grow in length and still meet the departure angle requirement. While it can meet the mobility requirements at the full 8000 lb GVW with larger tires, the best view of the 4x4 variant may be as a lower capacity vehicle sharing the same tires, suspension, and engine as the larger 6x6 hybrid-electric vehicle. As a member of a family of vehicles sharing common components, support across the platforms becomes a simpler logistics exercise.

The 6x6 hybrid versions shown represent the vehicle that hits all of the target objectives and maximizes the available cargo area of the MLR. The steering configuration is a full Ackerman steering with the center axle fixed and the opposed-phase rear axle steering at low speeds. To facilitate loading and unloading on the aircraft it is recommended to implement parallel-phase steering (crab steer) in the rear manually controlled by the driver. Small corrections to lateral position could be easily made while the vehicle is loaded providing the highest accuracy in lateral position for securing in the aircraft. See section 6.2 and 6.3 for steering analysis.

5.5. Comparison of Powertrain Configurations

Figure 5.5 illustrates graphically the different hybrid configurations discussed above.



Series Parallel Series-Parallel

Figure 5.5

5.6. Table of Various Configurations

Wheel Configuration	Steered axles	Powertrain Configuration
4 x 4	None, differential steering	Conventional Mechanical
6 x 6	1 conventional	Series Hybrid
8 x 8	1 & 2 for 6 x 6 or 8 x 8	Parallel Hybrid
	1 & 3 for 6 x 6	Series-Parallel Hybrid
	1, 2, 3 for 8 x 8 or crab	
	steering at low speed for 6 x 6	
	1, 2, 4 for 8 x 8	
	1, 2, 3, 4 crab steering at	
	low speed for 8 x 8	

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6. Comparison Studies

6.1. Mobility study

The objective of this analysis was to determine the optimum tire and wheel combinations to meet the desired mobility requirements. The targets were to achieve a one pass Vehicle Cone Index (VCI_1) of 15, a turning radius of 20 feet, and a GVW of 8000 pounds. The goal was to minimize the volume displaced by the wheel/tire combination (i.e., maximize the vehicle volume for the crew and cargo).

6.2. Steering Analysis

The RST-V has a required turning radius of 25 feet and a desired turning radius of 20 feet. In addition, it will be necessary to provide for low speed maneuverability to facilitate loading and unloading in the V-22, high speed directional and roll stability to provide safety at speed, and to package into a mechanically feasible system that allows for high wheel travel. Several steering systems were evaluated to determine their suitability given the layout of either four, six, or eight wheel configuration.

Skid steering has the advantage of minimizing the swept volume due to the wheels not turning relative to the chassis. The disadvantages are poor low speed maneuverability and increased motion resistance while turning. The skid steer was primarily eliminated due to the high length to width aspect ratio (approximately 3:1) of the vehicle as the side-to-side tractive force differential required to overcome the lateral scrubbing of the extreme fore and aft wheels becomes quite high.

Articulated steering is the best system for low speed maneuverability and minimum wheel encroachment from turning requirements. It allows for applying power through the wheels during turning, an advantage to mobility in soft and low tractive force soils. The disadvantages are that poor high speed stability, high mechanical complexity in the articulation joint, and it does not lend itself easily to high wheel travel suspension systems. The vehicle width increases significantly with small angles of steering, a problem when negotiating in the width restricted confines of the V 22 aircraft. It was not considered a suitable candidate for this effort.

Ackerman steer has the advantages of good low and high speed maneuverability, good high speed directional stability, and the ability to continuously power the wheels while turning. It has the highest drive efficiency as it has the minimum tire scrub during turning and it lends itself fairly easily to high wheel travel suspensions. The disadvantages are high wheel encroachment due the increased swept volume of the turned wheels and a moderate mechanical complexity of the steering and drive mechanisms. It was selected as the best candidate for RST-V.

6.3. Ackerman Steering Configuration and Turn Angle Analysis

The purpose of this exercise was to determine the turn angles required to achieve true Ackerman steering for various vehicle lengths and configurations to met both the required turn radius of 25 feet and the desired turn radius of 20 feet. Turn angles were limited to forty degrees as this is the practical limit of constant velocity joint drive shafts. Various wheelbases were examined for the four and six wheel variants explored. The drawings and calculation sheets which follow show the variants explored and the methods used. Details of steering analysis calculations are included in the appendices.

6.4. VCI_1 Calculation

Comparison studies were performed to optimize the tire/wheel combination to meet the desired mobility objectives for the vehicle. To find the tire/wheel combinations to met the Vehicle Cone Index (VCI_1) of 15 that provided the minimum volume impact, a module of the NRMMII was used which predicts VCI based on the inputted vehicle data. Since the maximum vehicle size envelope had been determined in the V-22 Fit Check study, these values of height, width, and ground clearance were used. The desired GVW of 8000 pounds was spread equally over the number of tires and axles. The assumptions were made that the vehicle would have an automatic transmission, locked differentials, single radial tires with a tire ply rating of 4 and no chains, and all wheels powered (with one 6x4 exception). All of the examples used a net horsepower of 264 which gives a HP/ton equivalent to JTEV and HTMMP.

With these vehicle parameters fixed, the comparison study was conducted with the following variables: number of axles (2, 3, & 4), tire section width (10.5, 12.5, & 14.5 inch), tire diameter (32, 36, & 40 inches), and tire deflection (20, 30, & 40%). This range of tire dimensions were selected as they are sizes common to this weight class of vehicle and are commercially available. The 20% tire deflection is typical of highway operating pressures and the 30 and 40% deflections represent levels achievable with Central Tire Inflation (CTI). It was not assumed at this stage that the vehicle would necessarily come equipped with CTI . This was designed to be a rough sort to understand what was required to meet the objectives.

VCI_1 values were calculated for various combinations of the Unified Soil Classification System (USCS). The VCI_1 typically used for comparisons are the fine grained soils which is the combined of SM (silty sands, sand-silt mixtures), SMSC (combination of SM with clayey sands, sand-silt mixtures), GM (silty gravels, gravel-sand-silt mixtures), and GMGC (combination of GM with clayey gravels, gravel-sand-clay mixtures). Values for VCI_1 for a given tire deflection were plotted against tire width for the various vehicle configurations. One graph was generated for each of the three tire deflections. Finding all of the vehicle combinations that meet the desired objective is a function of looking below the 15 VCI_1 line for a given tire deflection. A plot of number of wheels and tire diameter as a function of vehicle cone index vs. tire section width is provided in the appendices.

6.5. Wheel Displaced Volume Study

In order to determine the most space efficient configuration to meet the objectives, the volumes displaced by the tires were calculated based on the number of tires, tire width and diameter, turn angle for the steered axles, ground clearance, and jounce travel. A radial clearance allowance of 20% of the tire's radius and an axial clearance of 4 inches were used in the calculations. The turn angles used were based on the steering analysis for each of the configurations. The volumes were compared to the maximum volume determined by the V-22 Fit Check and expressed as a percentage.

6.6. Mobility Study Conclusions

From these analyses, several candidate configurations have been identified. The most appropriate will be dependent on the exact needs of the organization. The base assumptions for the following selections are based on 20% tire deflections (i.e., no CTI) as they are intended to be the most conservative to meet the objectives.

The 4x4 with 14.5 wide x 40 inch diameter tires meets the mobility criteria, however its wheelbase cannot go over 120 inches and still meet the 19 degree breakover angle requirement. The cargo bed could not be extended rearward and still meet the required departure angle, so the cargo area could not fully utilize the maximum achievable volume.

The 8x8 with 10.5 wide x 32 inch tires meets the mobility criteria and could utilize the maximum cargo area while achieving the desired approach and departure angles, but the volume and complexity penalties rule this configuration out as meriting further study.

The 6x6 with 14.5 wide x 32 inch tires meets the mobility criteria and could utilize the maximum cargo area while achieving the desired approach and departure angles, but may have difficulty with the requirement to traverse a 18 inch vertical step.

The 6x6 with 12.5 wide x 36 inch tires meets all of the criteria previously mentioned and deserves further study. With an Ackerman steering system with the center axle fixed and the rear axle in opposing phase, it can meet the turning radius objective. The rear axle steering is only necessary in low speed maneuvering and could be locked out above a given speed threshold. For loading and unloading on the aircraft, crab steering on the two rear axles could be implemented to allow for precise lateral positioning. The vehicle could utilize all of the available space in the V-22 and provide the largest cargo space while maintaining approach, departure, and breakover angle requirements. If it is deemed that CTI should be incorporated, the VCI_1 could be achieved at the 30% tire deflection with the narrower 10.5 inch wide tires, further increasing cargo space.

6.7. Mobility Filter

The primary challenge in the design of this vehicle is to maximize the overall "performance" in an off-road environment. Performance is defined as a combination of low speed mobility in extremely low traction environments such as deep mud, surf zone sand and wet clays and high speed ride quality over extremely rough terrain. It has been clearly demonstrated that increased speed correlates directly with increased survivability, therefore it is desirable to maximize the suspension travel, thereby minimizing the shock loads to the driver and the vehicle, allowing the driver to go faster. It is also clear that over the course of a mission scenario, a driver is more efficient if the shock and the vibration loads he is exposed to are reduced. There are also operational benefits that correlate with improved ride quality. There is, however, no real quantification of the advantages of this improved ride quality.

In order to evaluate the relative performance of the different conceptual vehicles, it is useful to have the ability to simulate the performance of a particular configuration and its effects on the driver over a given course. This allows us to predict the value of a suspension configuration vs. its measurable payload limitations and volume requirements. There are many hybrid vehicle simulators available which are based upon parametric models of the vehicle components and the interactions between them. Given a velocity as a function of time, the wind drag and rolling resistance are calculated to determine the total torque and speed required at the wheels to match that velocity profile. From the internal models, power distribution, efficiencies, and fuel consumption may then be calculated.

The limitation of these simulators is that they assume paved roads which have a smooth surface, very limited slip, and well-defined rolling resistance (a reasonable assumption for commercial vehicles) . Once the vehicle is brought off-road, the simple correlation between gross vehicle velocity and wheel speed/torque is no longer valid. Different soil conditions

and surface roughnesses present widely varying tire speed and torque values for the same vehicle velocity. AV designed a set of relations which used data from suspension testing which could provide an empirical relation for ride quality as a function of vehicle and course parameters. (See appendices for plots of driver absorbed power as a function of suspension travel and course rms.)

6.7.1 Test Plan

A test plan was developed to generate the required data to allow an empirical correlation to be developed for this class of vehicles (see Appendix A for details). The JTEV and HTMMP were outfitted with instruments to measure and record: vehicle speed, wheel torque, wheel speed, suspension position, throttle position and in the case of JTEV, commanded drive power and drive inverter voltage and current. The vehicles were driven on various types of terrain: pavement, soft sand, hard packed sand and silty, clayey sand with three different levels of roughness. Suitable terrain was identified for performing each test and the surface of each was surveyed. Each course was 600 ft long and the three rough courses - 0.576", 1.330" and 2.228" rms - were surveyed for elevation every foot. The vehicles were driven at a range of speeds: 10, 20, 30 and 40 mph, in both directions on each course.

The wheel travel of HTMMP was then limited to 10" and then to 5" for one complete series of tests on the rough courses to assess the effects of lower suspension travel on maximum attainable speeds. All of the data was recorded on a computer, and then analyzed to extract comparisons of: drive power, absorbed power of the driver, terrain type and roughness, and suspension travel.

Testing of the Articulated Electric Drive Trailer (AEDT) was planned to examine articulated, parallel hybrid-electric and 6X6 design permutations on off-road mobility and overall vehicle efficiency, but the AEDT was unavailable for use in testing due to a scheduling conflict with AEDT testing and refinement under NSWC contract N00167-96-C-0015.

6.7.2 Vehicle Instrumentation

JTEV and HTMMP were fitted with a full data acquisition package for measuring physical vehicle characteristics. Vehicles were fitted with the following sensor suite:

- Vertical accelerometer at drivers' seat to measure ride quality and compute driver absorbed power for each run.
- Suspension position sensors at each wheel to determine utilization of suspension travel and time spent in full bump and full droop positions.
- Throttle position sensor was used to determine torque request from driver. This data to be compared with torque delivered to the ground.
- Non-contacting fifth wheel was used to resolve actual vehicle velocity independent of slip between the tire/ground interface.
- Wheel speed sensors at each wheel were used to determine speed and percent slip at each wheel.
- Strain gages and sliprings were fitted to each axle to resolve torque transmitted to the ground. In conjunction with wheel speed data, mechanical power delivered from each wheel can be computed from this data. In the case of JTEV, mechanical power out can be compared to electrical power in to evaluate drivetrain efficiencies.

To record power flow throughout the vehicle, two approaches were used. Originally, bus voltage, accelerator pedal command, and commanded inverter power were recorded using data exported in a serial data format from each inverter.

This data was output at a rate of 4Hz, and did not allow synchronization between different inverter data streams. To overcome this issue, current and voltage sensors were later added to the JTEV power distribution system. The datalogger used for mechanical vehicle characteristics was subsequently used to acquire current and voltage data at higher rates.

6.7.3 Test Terrain

For testing in different RMS roughness conditions, three different courses were identified and surveyed in the Stoddard Valley area near Barstow, CA. Survey data was resolved to determine RMS surface roughness for each of the courses.

Sand testing at Camp Pendleton, CA allowed the use of both moist, compact sand in the surf zone and softer, dry sand above the high tide line.

6.7.4 Test Personnel and Equipment

Typical testing was performed with several representatives from each of AeroVironment and Rod Millen Special Vehicles present. A minimum test crew consisted of two engineers from AV and one engineer and two mechanics from RMSV. The RMSV test truck was utilized for transportation of all vehicles and support equipment.

6.7.5 Test History

November 4-5, 1996; Barstow

JTEV	- Low rms	- 20mph, 30mph, 40mph, 50mph
	- medium rms	- 20mph, 30mph, 40mph, 50mph
	- high rms	- 20mph, 30mph, 40mph
HTMMP 15" wheel travel		
	- Low rms	- 20mph, 30mph, 40mph, 50mph
	- medium rms	- 20mph, 30mph, 40mph, 50mph
	- high rms	- 20mph, 30mph, 40mph
HTMMP 10" wheel travel		
	- Low rms	- 20mph, 30mph, 40mph, 50mph
	- medium rms	- 20mph, 30mph, 40mph, 50mph
	- high rms	- 20mph, 30mph, 40mph

Strain gages were useless for the duration of the test due to incorrect gage selection. Several sliprings escaped their capture slides and rotated, breaking the lead-wires, one was demolished by an upper A-arm. All sliprings were repaired in the field. Data was collected without strain gages to validate the test plan. DA equipment and gather vertical acceleration at the drivers' seat. 5" suspension travel tests on HTMMP could not be performed due to repeated destruction of natural rubber bump stops. HTMMP transmission failed, terminating it's testing for the day. There had been a problem with the JTEV APU inverter faulting but leaving the engine running. Eventually the APU inverter failed terminating all testing for the day.

November 25-26 Barstow

JTEV	- Low rms	- 20mph, 30mph, 40mph, 50mph
	- medium rms	- 20mph, 30mph, 40mph, 50mph
	- high rms	- 20mph, 30mph, 40mph
HTMMP 15" wheel travel		
	- Low rms	- 20mph, 30mph, 40mph, 50mph
	- medium rms	- 20mph, 30mph, 40mph, 50mph
	- high rms	- 20mph, 30mph, 40mph

HTMMP suffered a failed transmission immediately after completing the 15" suspension travel test. 10" and 5" tests were not run. JTEV ran marginally throughout the entire test, but completed its scheduled runs.

December 10, 1996; Barstow

JTEV	- Low rms	- 20mph, 30mph, 40mph, 50mph
	- medium rms	- 20mph, 30mph, 40mph, 50mph
	- high rms	- 20mph, 30mph, 40mph
HTMMP 15" wheel travel		
	- Low rms	- 20mph, 30mph, 40mph, 50mph
	- medium rms	- 20mph, 30mph, 40mph, 50mph
	- high rms	- 20mph, 30mph, 40mph
HTMMP 10" wheel travel		
	- Low rms	- 20mph, 30mph, 40mph, 50mph
	- medium rms	- 20mph, 30mph, 40mph, 50mph
	- high rms	- 20mph, 30mph, 40mph
HTMMP 5" wheel travel		
	- Low rms	- 20mph, 30mph, 40mph, 50mph
	- medium rms	- 20mph, 30mph, 40mph, 50mph
	- high rms	- 20mph, 30mph,

Strain gages on JTEV failed again. The fifth wheel was problematic throughout the test. It was known to be stuffed into at least two bushes during the test, the second of which completely broke the signal connector off the case.

December 12, 1996; Camp Pendleton

JTEV	- Hard sand	- 10mph, 20mph, 30mph
	- Soft sand	- 10mph, 20mph, 30mph

Remainder of the near-term RST-V test suite was completed at Camp Pendleton. One strain gage failed on the very last test on JTEV, but all previous data is believed to be valid. HTMMP suffered a broken slipring, and the plan had been to swap one off JTEV, but there was insufficient daylight to complete the operation. JTEV operated well in the 100% humidity conditions in fog on the beach. Water was dripping off the roll bar during the entire test.

January 14, 1997: Barstow

JTEV	- Low rms	- 20mph, 30mph, 40mph, 50mph
	- medium rms	- 20mph, 30mph, 40mph, 50mph

The SGI was not functioning properly, but the photo shoot for R & T and the video shoot were completed regardless. JTEV was brought back to the test truck around 11am and the SGI was repaired quickly. Inverter #2 failed within 15 minutes. While the inverter was being removed for inspection, instrumented halfshafts and sliprings were installed. The ability to quickly change between non-instrumented and instrumented halfshafts allowed us

to fully demonstrate JTEV's capabilities to Road & Track without fear of damaging expensive data acquisition equipment. The inverter could not be fixed and at 3:30pm the decision was made to commence RMS testing running on a single motor/inverter.

All runs were completed on the low and medium RMS courses. Data from the strain gages on the new halfshafts appeared to be flawless. New current and voltage sensors on the JTEV power bus also appeared to be working well. During the first run on the high RMS course, the left front suspension upright separated at its lower mount. JTEV slid to a stop on its lower suspension arm and testing was declared over.

See appendices for data.

7. Failure Modes

The four different powertrains considered for this vehicle were compared to each other with respect to top level failures which are likely to occur during the operational life of the vehicle. These failure modes were classified as hard, soft (destructive), soft (limited), and soft. Hard failures caused the vehicle to stop functioning immediately when they came to the attention of the driver. Soft (destructive) failures indicate that the driver can continue to operate the vehicle after becoming aware of the failure, but components will be destroyed. This may be necessary in field operations, depending on conditions. Soft (limited) failures indicate that the vehicle will have limited range following the failure. Soft failures indicate that the vehicle will be able to operate with limited performance, but with reasonable range.

The analysis indicates that a series/parallel hybrid configuration may have the least number of failure modes, giving the vehicle the highest probability of completing its mission should any of these failures occur. Further analyses should be performed during the design phase of the RST-V to insure that the potential failure modes are minimized.

Failure Type	Conventional Drive	Series Hybrid Drive	Parallel Hybrid Drive	Series/Parallel Hybrid Drive
Loss of Coolant (HT)	Hard	Soft (Limited)	Soft (Limited)	Soft (Limited)
Loss of Coolant (LT)	N/A	Hard	Soft	Soft
Loss of Motor controller	N/A	Soft (single)	Soft	Soft
Loss of HV Bus (OC or short)	N/A	Hard	Soft	Soft
Loss of fuel	Hard	Soft (Limited)	Soft (Limited)	Soft (Limited)
Loss of 24V system	Hard	Hard	Hard	Hard
Loss of Engine Lubricant	Soft (destructive)	Soft (Limited)	Soft (Limited)	Soft (Limited)
Loss of Gearbox Lubricant	Soft (destructive)	Soft (single)	Soft (Destructive)	Soft (single)
Broken Half shaft	Soft	Soft	Soft	Soft
Loss of High Power Alternator/controller	N/A	Soft (Limited)	Soft	Soft

8. Lessons Learned

During the course of the RST-V program and JTEV/HTMMP testing, there were mechanical and electrical failures which suggested changes and improvements to future designs. These "lessons learned" are summarized here.

8.1. Reinforcement/Redesign of Skid Plates

The skid plates on both the JTEV and the HTMMP vehicles were damaged or torn off a number of times during off-road testing. These skid plates will require reinforcement, redesign, and probably both, to reduce or eliminate problems in the future.

The skid plates were fabricated from 1/4" thick aluminum plates with side flanges welded along their lengths. The plates were bolted to the tube frame below the differentials to protect them from being smashed during the severe off-road tests.

In some failures, the welded side flanges were torn clean off, while in others, the main plate was peeled back where an obstruction grabbed the edge of the plate.

Solutions included gusseting the skid plates, and extending them up the tube frame so that the edge of the plate cannot be caught by road obstructions. This will allow the obstruction to be deflected, rather than hooked by the edge of the plate.

8.2. Severe halfshaft loads

Loads on JTEV and HTMMP halfshafts approach the theoretical yield point of the shaft; this is common in design of lightweight, high performance vehicles. The major drawback of this design, for a test vehicle, is the apparent inability to reliably instrument the shaft in torsion. Strain levels at the shaft exceeded the specifications of even the most specialized strain gages. It was concluded that the only method of resolving this high a level of torsional strain was to reduce the amount of strain at the gage area.

Prior to the 1/14/97 test, special halfshafts were manufactured for JTEV. These shafts included a large diameter gaging area upon which strain gages were applied. The 7/8" nominal diameter shafts were expanded to 1 3/8" for a short length to proportionally reduce the torsional strain at the surface. These halfshafts were used during the 1/14/97 test, providing the previously unattainable ability to resolve torques as high as 15000 ft-lbs.

8.3. Torque Split

During initial testing with instrumented halfshafts, a front torque bias was noted. This apparently confirmed comments from Rod Millen during previous demonstrations suggesting that JTEV had excessive front axle torque.

Because the strain gages used to resolve torque were unreliable for the initial test phase, this information was noted but not addressed, pending additional, quantifiable data. Prior to the Barstow test on 1/14/97, JTEV was fitted with special, gageable halfshafts and current sensors for each traction motor. During a checkout drive near the RSMV facility, it was noted in both current draw and torque, the front axle motor/inverter pair was delivering nearly double the torque to the ground at the rear in some conditions. Despite the fact that JTEV has been operational for approximately 18 months, this is the first time this issue had been identified and quantified.

This discovery is powerful evidence supporting the need to fully instrument a development vehicle from the start of initial testing.

8.4. Human factors of APU Operating Strategy

The fuel economy benefits enabled by a series hybrid electric vehicle result from the ability to disassociate engine speed and throttle position from vehicle wheel speed and torque. In a conventional vehicle, the engine's speed is proportional to the vehicle's. This is because the engine is mechanically coupled to the wheels through a transmission (except when the vehicle is at or near standstill, when a torque converter or clutch disconnects the engine from the transmission). Because of this direct link between the engine and the wheels, a driver hears and feels the engine speed up as the vehicle accelerates, and hears and feels the engine slow down as the vehicle slows. The driver experiences a very direct correlation between vehicle behavior and engine behavior. This correlation is further reinforced because the vast majority of vehicles exhibit this behavior, and it has molded nearly every driver's expectations (except those familiar with continuously variable transmissions, such as found in snowmobiles.)

In a series hybrid electric vehicle, the engine is connected to an alternator which generates electricity. There is no mechanical connection between the engine and the wheels. The engine/alternator combination, or auxiliary power unit (APU), is controlled to deliver power based on overall vehicle requirements. The power commanded from the APU is based on the battery's present state of charge, a target state of charge, and the power demand of the traction inverters. Furthermore, the APU's throttle position and engine speed are controlled to achieve the most fuel efficient operating points of the engine. Because of this control method, there is no clear correlation between the vehicle's speed and the APU's speed.

This lack of correlation between vehicle speed and APU speed and throttle can be very unnerving to even experienced drivers. A typical example is a high power sprint, followed by a hard braking event. During the high power sprint, the APU will be running at a relatively high power point, while the battery pack will be delivering power as well, drawing down its state of charge. The high APU speed and throttle "feels" normal to the driver because the vehicle is moving under high power, and the engine is delivering high power. When the driver takes his foot off the accelerator pedal (whether or not he applies the brake pedal), he expects the engine speed to slow down and the throttle to close. However, since the battery pack was drawn down during the high power sprint, the APU algorithm commands the APU to keep delivering power, which is now applied into recharging the battery pack instead of into moving the vehicle. The effect on the driver is that although he's removed his foot from the accelerator pedal, and even applied the brakes, the engine is still racing, giving the impression that pedal commands are being ignored (or at least delayed). This behavior is even more disconcerting to passengers, who don't have the benefit of knowing what pedals are being depressed. Imagine entering a corner, expecting to slow down severely, and the engine continues to race. The passenger has the impression that the driver is applying full throttle into a turn, when in fact he's already released the accelerator pedal, and may even be braking.

There is no single solution. One alternative is training, in which drivers (and passengers) gain experience and learn the new paradigm. A second alternative is to add ergonomics into the algorithm, putting some correlation between accelerator pedal position and APU throttle and speed commands. This small level of correlation mustn't compromise the efficiency of the vehicle significantly, but experimentation may prove that some level of intelligent correlation can achieve the efficiency benefits of a series hybrid electric

powertrain, while giving expected sensory feedback to the driver. This sensory feedback may be critical in military operations, because unnecessary distractions to the driver could prove fatal.

8.5. Fans and Blowers

One of the two alternator cooling fans failed during testing after it had been shut down because of noise. It was thought, at the time, to be a failed bearing but is now suspected to have been debris which had entered the housing. Subsequent running of the vehicle with the fan disabled allowed back-flow of hot gasses from the exhaust mixing box to melt the plastic fan rotor. A screen has been put on the mixing box to prevent objects from entering the fan housings and the plastic fans rotors have been replaced with metal ones. No further such problems have occurred with these fans.

8.6. Lead Acid Battery Life Problems

The original battery pack installed in JTEV was a 30 module string of Hawker Genesis 26Ahr (nominal) 12V batteries. These were abused during the early part of the program, during which the pack was over discharged several times during early testing and development without being recharged fully. These factors lead to the pack being unable to perform up to expectations and to recurring problems with modules failing from time to time. Consequently this pack required more maintenance than would be acceptable for field operations.

In order to better manage the damaged pack, both the SmartGuards® and SmartGuard Interface were upgraded to improve reliability and usefulness in the system. The battery charging routine was changed radically from what was originally used. The battery used to be charged to approximately 420V (14 V per module) at low current. More expertise about management of this battery suggested a two step charge cycle consisting of four hours at 441V and 12A or more followed by one hour at 468V and 1 or 2A. This made a remarkable difference in the health of the pack. It became much better balanced allowing it to perform as well as it could in it's already damaged state.

The pack was originally assembled with interconnects made of two layers of copper braid with the ends tinned to prevent fraying. The mechanical strength of these interconnects proved insufficient to stand up to the repeated maintenance which the pack required and became thinner and thinner where they bolt on to the batteries. A new set of interconnects was made with three layers of braid and copper sleeves over their ends. These are much stronger and work much better.

A new battery pack was installed in the JTEV in the summer of 1996 under a DARPA funded program. This used same layout of 30 Genesis modules arranged slightly differently to simplify servicing. All the lessons learned about maintenance and SmartGuard operation have been applied to this pack and it is working well. Additionally, a scheduled maintenance program has been instituted consisting of a full conditioning charge, of the type described, every month. This is expected to keep the battery in good health but it is too early to know for sure. It is also unclear whether this maintenance charge would be practicable during field operations.

8.7. Vibration Hardening of Electrical Components:

Several failures and significant down time has resulted from the electronics on the JTEV being incapable of withstanding the vibrational environment. In general, electronic

components are fragile and special care is required to ensure that they can handle and operate in environments like those seen on the RST-V platform.

During testing, triaxial accelerometers were fitted to one of the inverter boxes and the vehicle chassis to resolve maximum G loads and frequency spectrum over typical terrain. This data was only partially reduced, but did indicate that even over moderate terrain, components should be designed to reliably withstand up to 4G peaks. Fourier analysis was not conducted on this data to date, but may be evaluated at a later time.

During the mobility filter testing the controller for the low temperature coolant fan was completely destroyed due to the vibrational environment. The commercially purchased controller was not designed to handle any serious vibration. The large capacitors involved in the control of the brushless DC fan motor were supported only by their small electrical leads. No other physical support was supplied for these components. In the vibrational environment seen during testing of the JTEV, the weight of the capacitor undergoing large G forces caused the leads to fatigue. Once the leads had fatigued and broken, they continued to make contact with other parts of the circuit board and the high voltage difference and large current surges caused utter destruction of the device.

After the failure of this controller, the similar controller used to control the APU coolant fan was ruggedized to withstand the vibrational environment. The capacitors in the controller where physically restrained with silicon adhesive so that the vibrational force of the capacitors did not stress the electronic leads. Following the fix of the second motor controller significant testing of the JTEV was conducted and no failure was observed.

The major lesson extracted from this failure is that all commercially purchased components need to have their large mass electronic components restrained in addition to those methods by which they were commercially manufactured, and other restraint standards apply. This will be particularly important as the military attempts to use more components which are common with the commercial sector.

In a developmental program such as the JTEV, ease of modification of electronics is extremely important. Towards this end, all control chips are placed in sockets. This approach has problems, however. Several periods of improper function of electronics have occurred due to vibration of the components. These failures may not physically damage any components but will cause the system to not work correctly. This typically results from a chip that has vibrated loose and is operating but not in the correct fashion. This has occurred on several of the circuit boards on the JTEV. The typical solution to this problem is the disassemble the offending component and reinsert the problematic chip. Several methods have been tried with, varied success, to restrain components. Physically gluing the chips into the sockets has proven reasonably successful as long as no movement can occur after the gluing. Some chips can not be glued as they occasionally need to be replaced to update the software which runs the system. These components are very difficult to prevent from vibrating out of their sockets and if not checked can occasionally cause down time.

One of the major lessons that is reinforced from these experiences is the necessity of surface mount components in final system hardware. This totally eliminates the chip and socket interface that has cause so many problems in this system. Even chips that contain software can be surface mounted if they use Electronically Erasable Programmable Read Only Memory (EEPROM). This would allow reprogramming of the chip without replacement or removal from the circuit board. Large surface mounted components should also be physically restrained with silicon adhesive or other means at the time of mounting to ensure adequate resistance to vibrational loads. Another lesson that can be taken from these

experiences is the orient the electronic circuit boards as to reduce the stress on the components in the direction of most violent vibrations.

Future development of vehicles with this type of vibrational environment should include time and budget for testing of electronic components on vibration test table with characteristic vibrational patterns to determine where failures will occur. This way problems can be corrected early and prevent vehicle down time and damage to other components.

8.8. EMI Characteristics

The electromagnetic interference (EMI) generated by the JTEV systems changes dramatically depending on what state the vehicle is in. If the high voltage systems are not operating there is almost no EMI emitted. Each of the high power systems causes EMI of varying levels. The DC-DC converter emits small level of EMI when it is engaged, any time the key is turned on. The electric motor drives emit a large level of EMI when the system is put into a driving state. The magnitude of the system interference is related to the proximity to the power wires and components, and the degree of shielding. The APU also emits a large level of EMI when it is running which is strongest in the proximity of the power cables from the alternator to the inverter.

The EMI generated by JTEV has cause problems in the past with instrumentation readings for the vehicle. Special care has been required to shield the instrumentation from this interference. The proper way to approach this problem however is to study the exact sources and the eliminate this radiation of noise. Detailed study of the sources and different shielding approaches could result in a vehicle which is friendly to on-board instrumentation and sensors as well hard to identify externally from the interference it creates. Another approach is the study ways to eliminate the effect of EMI within the vehicle on internal systems. Use of fiber-optic communication should be studied to prevent EMI effects on instrumentation within the vehicle. This type of system would also be resistant to Electromagnetic Pulse effects.

8.9. Thorough Instrumentation Is Critical For Development

Debugging a control system can be somewhat of a mystery if there is insufficient instrumentation. The interaction of different parts of software can be sometime unpredictable. The only way to determine if the code is functioning correctly is to know what it is 'thinking'. This requires knowing what data the control system is receiving to determine if it is functioning as intended by the programmer. In additional, independent instrumentation is required to determine of the control system is receiving the correct information at all.

This points to two types of instrumentation which are needed. One type of instrumentation is required to interact with the control system to keep track of what it is thinking. Another type of instrumentation is required to keep track of what is actually happening with the system. This includes information like drive train output, electrical input, speed, temperatures, etc. In a development program it is important to design this type of instrumentation into a system rather than adding it on after the fact. This helps integrate the instrumentation, makes it easier to use, and more accurate. In addition, it means that it can be used from the beginning of the program instead of being added on later to determine what is actually happening when nothing can really be changed. The design cost of instrumentation is small since it can always be removed as the a system progresses toward production but it is very hard to add later in the design process.

8.10. Bump Stops

In fitting HTMMP with suspension limitation hardware, it was originally assumed that rubber bump stops would be sufficient to limit suspension travel. In short suspension travel configurations, (10" and 5"), these stops were readily destroyed, particularly during medium and high RMS course testing. Polyurethane bump stops were used for subsequent testing with marginal results. There is significant kinetic energy in a fast-moving vehicle chassis. We learned that this energy is not readily dissipated without adequate shock absorber and suspension travel.

8.11. Repeatable testing is good testing

Great efforts were taken during testing to ensure that variables were kept constant when required by the test matrix. A professional driver (Rod Millen) was used to reduce the variation of tire placement and speed between subsequent runs. Data acquisition equipment was calibrated regularly during testing.

The only variable that truly escaped our abilities to compensate for was weather. We learned that winter, even in California, is a poor time to commence extensive outdoor testing.

Additionally, we learned that even the most repeatable tests in naturally occurring terrain are not always repeatable enough. It would have been desirable to perform half-round bump tests at different speeds to determine effects of different suspension configurations.

8.12. Bump Steer

During the extended testing required to gather data for the mobility filter, it was noticed that JTEV has a significant amount of what is commonly referred to as bump steer. Bump steer is an effective change in toe as the suspension swings through its travel. It is something that can be easily corrected through iterative adjustment of key suspension links. Its presence in an off-road vehicle adds instability in rough terrain; the wheels effectively steer when in full droop or bump. The physical manifestation of this phenomenon is a vehicle instability after landing from a jump.

8.13. Alternator configuration

The APU alternator in the JTEV is a custom built unit from Onan Corp. It is a permanent magnet, brushless design with a maximum rated output of 60 kW. The rotor was built to be mounted directly on the end of the crankshaft of the diesel engine, replacing the flywheel, and it uses the engine main bearings alone for support. It is contained in a housing which locates the stator and is cooled by forced air from one mechanical and two electrical fans.

The bearing-less layout had been a cause for concern during conceptual design. It was known that if, under high vertical loads, the rotor touched down on the stator, or even deflected significantly, an unstable whirling mode would be set up in the rotor causing it to repeatedly collide with the stator and destroy itself rapidly. The rotor had to be designed very carefully and the whole assembly constructed to fine tolerances to prevent this whirl mode from occuring. As designed, the alternator was predicted to withstand 20G shocks without touchdown.

During testing, the vehicle has been subject to some very high vertical loads (shocks greater than 10G). The suspension has been bottomed many times and both front and rear skid

plates have been torn off from severe contact with the ground. So far nothing has induced the alternator rotor to hit the stator, confirming the initial analysis of the rotor design used in this alternator configuration.

There have been three failures of the alternator during testing. Of these one was due to overheating, one from an electrical fault and one from a mechanical fault. In all cases, the problem was identified and solved by system or hardware modification. The reliance on the engine bearings to support the rotor appears to have been justified although the alternator as a whole has not been the most reliable component on the vehicle. It may be worthwhile examining other details of it's design for a next generation vehicle.

8.14. Shock valving

It was noted in testing that JTEV does not fully utilize its available suspension travel. Additionally, it has a kick in the rear, an indication of improper shock valving. A full iterative tune of the JTEV suspension is required to optimize spring rates and damping values for all four wheels.

8.15 Payload

During original testing, sandbags were used as ballast to bring the vehicles to GVW. These proved ineffective, as they were difficult to properly restrain in rough courses. If not restrained, they would either leak sand, changing their weight, or flop around the cargo area, severing data acquisition wires and posing a hazard to driver and passenger. The solution was to use steel plates of known weight, firmly bolted into the cargo bay of each vehicle. This provided a constant, safe means of simulating a full vehicle cargo.

9. Possible Common Parts with LSV

There are many possible components that could be designed to be cross-platform compatible for many of the military light vehicles. Most notably, the RST-V could share components with the proposed Light Strike Vehicle to aid in logistics including:

Suspension Components - Wheels, brakes, uprights, control arms, shocks and spring systems are the most feasible to generate across platforms.
Consumables - Common consumables such as coolants, lubricating oils, fuels, tires, and brake pads could be shared between LSV and RST-V.
Steering Components - It would be desirable to use the same primary steering system in both platforms. The steering rack, tie rods, steering arms, and stationary tie rod points could be shared.
Ride Height and CTI - As with the rest of the suspension, any provisions for ride height and central tire inflation could be shared.
Final Drive and Differential- Using the same constant velocity joints, drive axles, differential components would be possible since the vehicle widths would be consistent and the uprights and drive flanges could be the same.
Driver Interface and Controls - There would be a distinct advantage in using the same seats, steering wheels, pedal assemblies, gauge layouts and interfaces to both provide ease of logistical support and the driver's adaptability across platforms.
Common Maintenance Tools - The same mechanical tools can be used. Specialized troubleshooting equipment may be required for the electric motor controls.

10. Summary and Recommendations

The studies performed during this program can be narrowed down to three areas for consideration; suspension travel, axle number, and powertrain configuration.

Suspension travel is the prime consideration in reducing driver absorbed power. The greater the suspension travel, the lower the driver absorbed power, and therefore the greater speed (or longer distance, depending on mission requirements) one can travel over a given terrain. This feature should be maximized in any vehicle in which mobility is considered to be a critical performance parameter to insure both speed and endurance in operations.

The number of axles determines the breakover angle, tire size, steering configuration, and traction characteristics of the vehicle. When accounting for the mass, volume, ingress, and egress constraints, the six wheeled version meets all of the design objectives, while maximizing the available cargo area of the MLR.

The series-parallel powertrain represents the best alternative for this vehicle, enabling the best characteristics of hybrid powertrains (efficient operation, high motor torque at low speed, the option of quiet all-electric operation) with the redundancy of operating via a direct mechanical link to the engine. This configuration has the fewest hard failure modes, and those that exist can be mitigated in next-generation designs.

The general characteristics which are recommended for the vehicle are as follows:

Dimensions	
Height	65"
Width	65"
Length	212"
Wheelbase	119/162"
Payload Volume	63.6 ft3
APU	
Volume	12 ft3
Weight	550 lbs
Power rating	90kW
Battery Pack	
Type	TBD
Size	8 kWhr
Nominal Voltage	360V
Power rating	150kW
Transmission/Differentials	
Type	Active
gear ratios	TBD
Electric drive motors	
Type	Induction
Power rating (per axle)	30/100kW
Number	TBD
Wheels/tires and suspension	
Number and size	6, 36"x12.5"
Swept volume	88.4 ft3
Travel	18"
Ground clearance	16"
VCI	15
Steering	
Type	Pwr Asst R&P
Number of axles steered	TBD
Turning radius	20'

Appendices

A) Suspension Test Plan

B) Representative Mobility Data from Suspension Testing
   - Representative Data Acquisition Output
   - Relevant data plotted vs. time
   - Driver absorbed power

C) Example Notional Vehicle (6 X 6)
   - Side View
   - Top View
   - Litter/Personnel Carrier
   - Sensor Carrier

D) Weight and Volume Study Data

E) Ackerman Steering Analysis

F) Vehicle Cone Index Graph (representative)

G) Wheel Displaced Volume and Suspension Analysis

H) Drivetrain Configuration Considerations

Appendix A Test Plan

Reconnaissance / Surveillance / Acquisition Vehicle
Mobility & Energy Efficiency Modeling
using the Configuration Performance Simulator (CPS)

1. **Purpose: Accurate prediction of the following vehicle performance parameters through the use of various vehicle configurations run on collected mobility trips.**
   a) Vehicle energy efficiency / range with suspension losses
   b) Propulsion system performance
   c) Rough terrain, high speed mobility (power or control limited)
   d) Soft soil mobility
2. **Software Development**
   a) Mobility Outputs (Additional to Standard AV Simulator Outputs)
      i) Energy Efficiency and Range compared to same speeds and grades on pavement
      ii) Propulsion system performance compared to same speeds and grades on pavement
      iii) Over-all ride quality value (criteria? absorbed power at driver seat attachment? absorbed power at driver?)
      iv) Speed following error flag / following ability compared to 1 for tested vehicle (<1 means it couldn't keep up, >1 means it could do more; only applicable to all-out "dash" trips.)
      v) Soft soil NOGO error flag ???
3. **Testing of Baseline Vehicles**
   a) Test Plan - See Trip Matrix
   b) Mobility Trip Parameters: Basic DAQ Items (to become trip input parameters)
      i) Dynamic parameters (21 DAQ channels)
         a) Vehicle velocity: 1 channel Non-contacting 5th wheel
         b) 6x wheel speed: 6 channels Pick-up at torque sensor slip rings
         c) 6x wheel torque: 6 channels Torque sensors
         d) 6x suspension pos.: 6 channels Rotary pot
         e) Pedal position: 1 channel Throttle pot
         f) Event marker 1 channel Momentary push-button
      ii) Static Parameters
         a) Grade: Surveying
         b) RMS surface roughness: Surveying
         c) Soil classification Observation
         d) Cone Index (CI) Cone penetrometer
         e) Remolding Index (RI) Observation
         f) Radius of curvature: Course layout
4. **Model Calibration and Validation**
   a) Reduction of Test Data for Mobility Model Validation and Trip Generation
5. **Concept Evaluation**
   a) Simulate Multiple Concepts on Collected Mobility Trips to Evaluate Powertrain and Suspension Designs

Trip Matrix

1. All trips have one event marker channel, one vehicle speed channel, and one pedal position channel.
2. The grade of each trip is to be measured and recorded.
3. The actual RMS surface roughness, Cone Index, and Remolding Index are to be measured and recorded for each trip.

Trip #	Location	Course	Vehicle	Suspension Limit	Vehicle Speed	Radius	Total DAQ Channels (1)
1	Pendleton	Soft Sand	JTEV	15"	10 mph	na	15
2	Pendleton	Hard Pack Sand	JTEV	15"	10 mph	na	15
3	Pendleton	Soft Sand	JTEV	15"	20 mph	na	15
4	Pendleton	Hard Pack Sand	JTEV	15"	20 mph	na	15
5	Pendleton	Soft Sand	JTEV	15"	30 mph	na	15
6	Pendleton	Hard Pack Sand	JTEV	15"	30 mph	na	15
7	Pendleton	Soft Sand	HTMMP	15"	10 mph	na	15
8	Pendleton	Hard Pack Sand	HTMMP	15"	10 mph	na	15
9	Pendleton	Soft Sand	HTMMP	15"	20 mph	na	15
10	Pendleton	Hard Pack Sand	HTMMP	15"	20 mph	na	15
11	Pendleton	Soft Sand	HTMMP	15"	30 mph	na	15
12	Pendleton	Hard Pack Sand	HTMMP	15"	30 mph	na	15
13	Pendleton	Soft Sand	HTMMP/AEDT	15"	10 mph	na	21
14	Pendleton	Hard Pack Sand	HTMMP/AEDT	15"	10 mph	na	21
15	Pendleton	Soft Sand	HTMMP/AEDT	15"	20 mph	na	21
16	Pendleton	Hard Pack Sand	HTMMP/AEDT	15"	20 mph	na	21
17	Pendleton	Soft Sand	HTMMP/AEDT	15"	30 mph	na	21
18	Pendleton	Hard Pack Sand	HTMMP/AEDT	15"	30 mph	na	21
19	Barstow	Low RMS	JTEV	15"	20 mph	na	15

Trip #	Location	Course	Vehicle	Suspension Limit	Vehicle Speed	Radius	Total DAQ Channels (1)
20	Barstow	Low RMS	JTEV	15"	35 mph	na	15
21	Barstow	Low RMS	JTEV	15"	50 mph	na	15
22	Barstow	Medium RMS	JTEV	15"	20 mph	na	15
23	Barstow	Medium RMS	JTEV	15"	35 mph	na	15
24	Barstow	Medium RMS	JTEV	15"	50 mph	na	15
25	Barstow	High RMS	JTEV	15"	20 mph	na	15
26	Barstow	High RMS	JTEV	15"	35 mph	na	15
27	Barstow	High RMS	JTEV	15"	50 mph	na	15
28	Barstow	Low RMS	HTMMP	5"	20 mph	na	15
29	Barstow	Low RMS	HTMMP	5"	35 mph	na	15
30	Barstow	Low RMS	HTMMP	5"	50 mph	na	15
31	Barstow	Low RMS	HTMMP	10"	20 mph	na	15
32	Barstow	Low RMS	HTMMP	10"	35 mph	na	15
33	Barstow	Low RMS	HTMMP	10"	50 mph	na	15
34	Barstow	Low RMS	HTMMP	15"	20 mph	na	15
35	Barstow	Low RMS	HTMMP	15"	35 mph	na	15
36	Barstow	Low RMS	HTMMP	15"	50 mph	na	15
37	Barstow	Medium RMS	HTMMP	5"	20 mph	na	15
38	Barstow	Medium RMS	HTMMP	5"	35 mph	na	15
39	Barstow	Medium RMS	HTMMP	5"	50 mph	na	15
40	Barstow	Medium RMS	HTMMP	10"	20 mph	na	15
41	Barstow	Medium RMS	HTMMP	10"	35 mph	na	15
42	Barstow	Medium RMS	HTMMP	10"	50 mph	na	15
43	Barstow	Medium RMS	HTMMP	15"	20 mph	na	15
44	Barstow	Medium RMS	HTMMP	15"	35 mph	na	15

Trip #	Location	Course	Vehicle	Suspension Limit	Vehicle Speed	Radius	Total DAQ Channels (1)
45	Barstow	Medium RMS	HTMMP	15"	50 mph	na	15
46	Barstow	High RMS	HTMMP	5"	20 mph	na	15
47	Barstow	High RMS	HTMMP	5"	35 mph	na	15
48	Barstow	High RMS	HTMMP	5"	50 mph	na	15
49	Barstow	High RMS	HTMMP	10"	20 mph	na	15
50	Barstow	High RMS	HTMMP	10"	35 mph	na	15
51	Barstow	High RMS	HTMMP	10"	50 mph	na	15
52	Barstow	High RMS	HTMMP	15"	20 mph	na	15
53	Barstow	High RMS	HTMMP	15"	35 mph	na	15
54	Barstow	High RMS	HTMMP	15"	50 mph	na	15
55	Barstow	Low RMS	HTMMP/AEDT	15"	20 mph	na	21
56	Barstow	Low RMS	HTMMP/AEDT	15"	35 mph	na	21
57	Barstow	Low RMS	HTMMP/AEDT	15"	50 mph	na	21
58	Barstow	Medium RMS	HTMMP/AEDT	15"	20 mph	na	21
59	Barstow	Medium RMS	HTMMP/AEDT	15"	35 mph	na	21
60	Barstow	Medium RMS	HTMMP/AEDT	15"	50 mph	na	21
61	Barstow	High RMS	HTMMP/AEDT	15"	20 mph	na	21
62	Barstow	High RMS	HTMMP/AEDT	15"	35 mph	na	21
63	Barstow	High RMS	HTMMP/AEDT	15"	50 mph	na	21
64	Pomona	Paved	JTEV	15"	20 mph	50'	15
65	Pomona	Paved	JTEV	15"	30 mph	50'	15
66	Pomona	Paved	JTEV	15"	40 mph	50'	15
67	Pomona	Paved	JTEV	15"	20 mph	100'	15
68	Pomona	Paved	JTEV	15"	30 mph	100'	15
69	Pomona	Paved	JTEV	15"	40 mph	100'	15

Trip #	Location	Course	Vehicle	Suspension Limit	Vehicle Speed	Radius	Total DAQ Channels (1)
70	Pomona	Paved	JTEV	15”	20 mph	150’	15
71	Pomona	Paved	JTEV	15”	30 mph	150’	15
72	Pomona	Paved	JTEV	15”	40 mph	150’	15
73	Pomona	Paved	HTMMP	15”	20 mph	50’	15
74	Pomona	Paved	HTMMP	15”	30 mph	50’	15
75	Pomona	Paved	HTMMP	15”	40 mph	50’	15
76	Pomona	Paved	HTMMP	15”	20 mph	100’	15
78	Pomona	Paved	HTMMP	15”	30 mph	100’	15
79	Pomona	Paved	HTMMP	15”	40 mph	100’	15
80	Pomona	Paved	HTMMP	15”	20 mph	150’	15
81	Pomona	Paved	HTMMP	15”	30 mph	150’	15
82	Pomona	Paved	HTMMP	15”	40 mph	150’	15
83	Pomona	Paved	HTMMP/AEDT	15”	20 mph	50’	21
84	Pomona	Paved	HTMMP/AEDT	15”	30 mph	50’	21
85	Pomona	Paved	HTMMP/AEDT	15”	40 mph	50’	21
86	Pomona	Paved	HTMMP/AEDT	15”	20 mph	100’	21
87	Pomona	Paved	HTMMP/AEDT	15”	30 mph	100’	21
88	Pomona	Paved	HTMMP/AEDT	15”	40 mph	100’	21
90	Pomona	Paved	HTMMP/AEDT	15”	20 mph	150’	21
91	Pomona	Paved	HTMMP/AEDT	15”	30 mph	150’	21
92	Pomona	Paved	HTMMP/AEDT	15”	40 mph	150’	21

Turning / Acceleration Performance Test Procedure:

1. Radius of curvature is from center of lane; curve covers approximately _ of a full circle; entry and exits are tangent.
2. Lane is 15' wide with coned borders - vehicle must safely stay within borders to complete a successful run.
3. Enter the corner at approximately the specified speed (20, 30, or 40 mph), using none or light throttle.
4. Begin accelerating hard from the marker at mid curve, about 45 degrees into the 90 degree turn.
5. Accelerate at the safest possible rate until 60 mph is reached, before or after exiting turn.
6. Record speed at entry tangent, and time from mid curve to 60 mph.

Mobility Testing Trip Report

Trip # ________________

Trip Location ________________

Course ________________

Vehicle ________________

Suspension Limit (in) ________________

Vehicle Speed (mph) ________________

Actual RMS Roughness ________________

Soil Classification ________________

Cone Index ________________

Remolding Index ________________

Radius of Turn (ft) ________________

Mid radius to 60 mph (s) ________________

Events / Comments ______________________________

Unified Soil Classification System (Summarized)

GW	well-graded, clean gravels, gravel-sand mixtures
GP	poorly-graded clean gravels, gravel-sand mixtures
GM	silty gravels, poorly graded gravel-sand-silt
GC	clayey gravels, poorly-graded gravel-sand-clay
SW	well-graded clean sands, gravely sands
SP	poorly graded clean sands, sand-gravel mix
SM	silty sands, poorly graded sand-silt mix
SM-SC	sand-silt-clay mix with slightly plastic fines
SC	clayey sands, poorly graded sand-clay mix
ML	inorganic silts and clayey silts
ML-CL	mixture of organic silt and clay
CL	inorganic clays of low-to-medium plasticity
OL	organic silts and silt-clays, low plasticity
MH	inorganic clayey silt, elastic silts
CH	inorganic clays of high plasticity
OH	organic and silty clays
Pt	peat and other highly organic soils

Appendix B Representative Mobility Data

JTEV TESTING 11/26/96

LOW RMS COURSE (0.576)

Time	Speed	Throttle Position	Accelero-meter	LF Wheel speed	LF Wheel torque	LF Sus Pos	RF Wheel speed	RF Wheel torque	RF Sus Pos	LR Wheel speed	LR Wheel torque	LR Sus Pos	RR Wheel speed	RR Wheel torque	RR Sus Pos
0.01	41.682	32.374	0.9	44.316	387.534	7.419	0.012	509.909	7.348	42.541	19.339	6.442	42.997	5.937	7.897
0.02	41.604	32.374	0.665	44.328	425.595	7.419	0.012	516.184	7.304	42.541	20.413	6.364	42.997	4.75	7.765
0.03	41.541	32.374	0.864	44.304	453.853	7.442	0.048	504.206	7.196	42.505	18.265	6.286	43.069	5.937	7.662
0.04	41.526	30.456	0.985	44.316	491.337	7.628	0.024	469.413	7.13	42.505	19.339	6.208	43.009	0.594	7.544
0.05	41.432	30.456	0.828	44.256	514.405	7.791	0.048	434.621	7.022	42.505	11.281	6.156	43.045	5.937	7.426
0.06	41.354	30.456	0.888	44.304	516.711	7.884	0.012	401.539	7	42.529	19.339	6.052	43.045	0	7.397
0.07	41.385	30.456	1	44.28	521.325	7.907	0.012	387.851	6.886	42.505	18.265	6.056	43.069	-5.288	7.368
0.08	41.354	30.456	1.057	44.328	515.558	8	0.012	389.562	6.932	42.505	15.041	6.056	43.033	-10.575	7.309
0.09	41.354	30.456	0.997	44.328	505.178	8	0.048	404.391	7	42.505	13.43	6	43.081	-11.633	7.25
0.1	41.323	30.456	1.133	44.328	498.257	8.045	0.012	408.954	7.174	42.541	10.744	6.056	43.033	-4.23	7.191
0.11	41.307	30.456	0.912	44.364	501.718	8.136	0.012	409.525	7.37	42.517	8.595	5.887	43.081	-6.874	7.074
0.12	41.401	30.456	1.009	44.388	512.675	8.273	0.024	405.532	7.674	42.517	10.744	5.634	43.045	-14.805	7.015
0.13	41.495	30.456	0.813	44.412	512.098	8.318	0	402.68	7.891	42.505	12.355	5.493	43.093	-29.611	6.813
0.14	41.62	30.456	0.912	44.352	506.908	8.341	0.012	391.843	8.133	42.505	2.149	5.465	43.093	-43.887	6.733
0.15	41.745	30.456	1.012	44.376	502.294	8.409	0.048	383.858	8.267	42.505	1.074	5.437	43.105	-51.29	6.68
0.16	41.76	30.456	0.961	44.352	504.024	8.5	0.036	370.74	8.489	42.505	-2.334	5.408	43.093	-53.934	6.64
0.17	41.807	30.456	0.952	44.34	498.257	8.523	0.012	351.917	8.622	42.529	0	5.408	43.117	-63.98	6.6
0.18	41.916	30.456	1.03	44.352	491.337	8.682	0	331.384	8.778	42.553	1.074	5.408	43.105	-69.797	6.6
0.19	42.057	30.456	1.036	44.304	480.38	8.773	0	321.688	8.8	42.601	-0.583	5.465	43.117	-68.21	6.6
0.2	42.229	30.456	1.154	44.352	472.883	8.886	0	317.695	8.844	42.661	3.223	5.577	43.117	-65.038	6.573
0.21	42.354	30.456	1.109	44.352	465.386	9.095	0.012	318.836	9.103	42.697	0.537	5.718	43.105	-55.52	6.52
0.22	42.479	30.456	1.444	44.388	457.313	9.19	0.012	313.132	9.256	42.781	2.149	5.859	43.105	-47.589	6.52
0.23	42.667	30.456	1.29	44.364	442.319	9.214	0	300.584	9.308	42.769	4.298	6.056	43.129	-34.37	6.48
0.24	42.823	30.456	1.269	44.4	437.705	9.19	0.012	299.443	9.462	42.877	17.727	6.169	43.141	-31.197	6.547
0.25	42.854	30.456	1.157	44.352	440.589	9.119	0.012	302.295	9.513	42.913	24.711	6.312	43.201	-22.208	6.6
0.26	42.932	30.456	1.172	44.364	449.816	9.095	0	309.71	9.513	42.925	20.413	6.416	43.237	-25.381	6.72
0.27	42.917	28.537	0.927	44.364	458.466	9.095	0	319.977	9.436	42.961	16.116	6.519	43.261	-34.898	6.893
0.28	42.839	28.537	1.172	44.376	465.963	9.095	0.012	325.68	9.513	42.961	9.67	6.675	43.333	-38.071	7.235
0.29	42.932	28.537	0.973	44.376	482.11	9.024	0.012	344.503	9.436	43.009	15.041	6.792	43.333	-40.715	7.603
0.3	42.979	28.537	1.221	44.352	487.877	9	0.012	359.903	9.462	43.105	22.025	7.086	43.381	-31.726	7.868
0.31	42.995	28.537	1.012	44.424	492.491	9	0	370.74	9.385	43.105	19.876	7.257	43.405	-23.794	8.149
0.32	43.073	28.537	1.196	44.424	491.337	8.886	0.048	373.591	9.385	43.165	20.951	7.429	43.429	-19.035	8.403
0.33	43.104	26.619	1	44.436	489.03	8.886	0	383.858	9.308	43.201	24.711	7.629	43.477	-21.679	8.627
0.34	43.104	26.619	1.227	44.484	489.03	8.864	0.024	386.139	9.256	43.273	19.876	7.8	43.525	-10.575	8.776
0.35	43.136	26.619	1.073	44.544	479.803	8.886	0	396.406	9.179	43.333	17.19	8	43.573	-4.759	8.851
0.36	43.214	26.619	1.317	44.544	475.19	8.864	0.012	400.969	9.077	43.357	17.727	8.162	43.62	-4.23	9.016
0.37	43.245	26.619	1.227	44.604	465.386	8.864	0.012	400.399	8.8	43.441	15.041	8.378	43.68	-8.989	9.129
0.38	43.276	26.619	1.414	44.64	461.349	8.864	0.048	391.843	8.822	43.465	22.025	8.541	43.728	-3.701	9.21
0.39	43.432	26.619	1.29	44.664	456.736	8.886	0.012	388.421	8.711	43.513	19.339	8.649	43.812	-8.46	9.274
0.4	43.479	26.619	1.375	44.7	455.583	8.886	0.012	386.139	8.733	43.537	22.562	8.703	43.86	-5.816	9.371
0.41	43.432	26.619	1.178	44.712	449.239	9.048	0	382.147	8.667	43.584	18.265	8.73	43.908	-2.644	9.419
0.42	43.479	24.7	1.172	44.736	437.705	9.095	0.012	371.31	8.733	43.584	22.025	8.757	43.92	2.375	9.419
0.43	43.495	24.7	1.193	44.736	419.251	9.095	0.048	354.199	8.689	43.584	20.413	8.757	43.98	0.594	9.452

JTEV TESTING 11/26/96

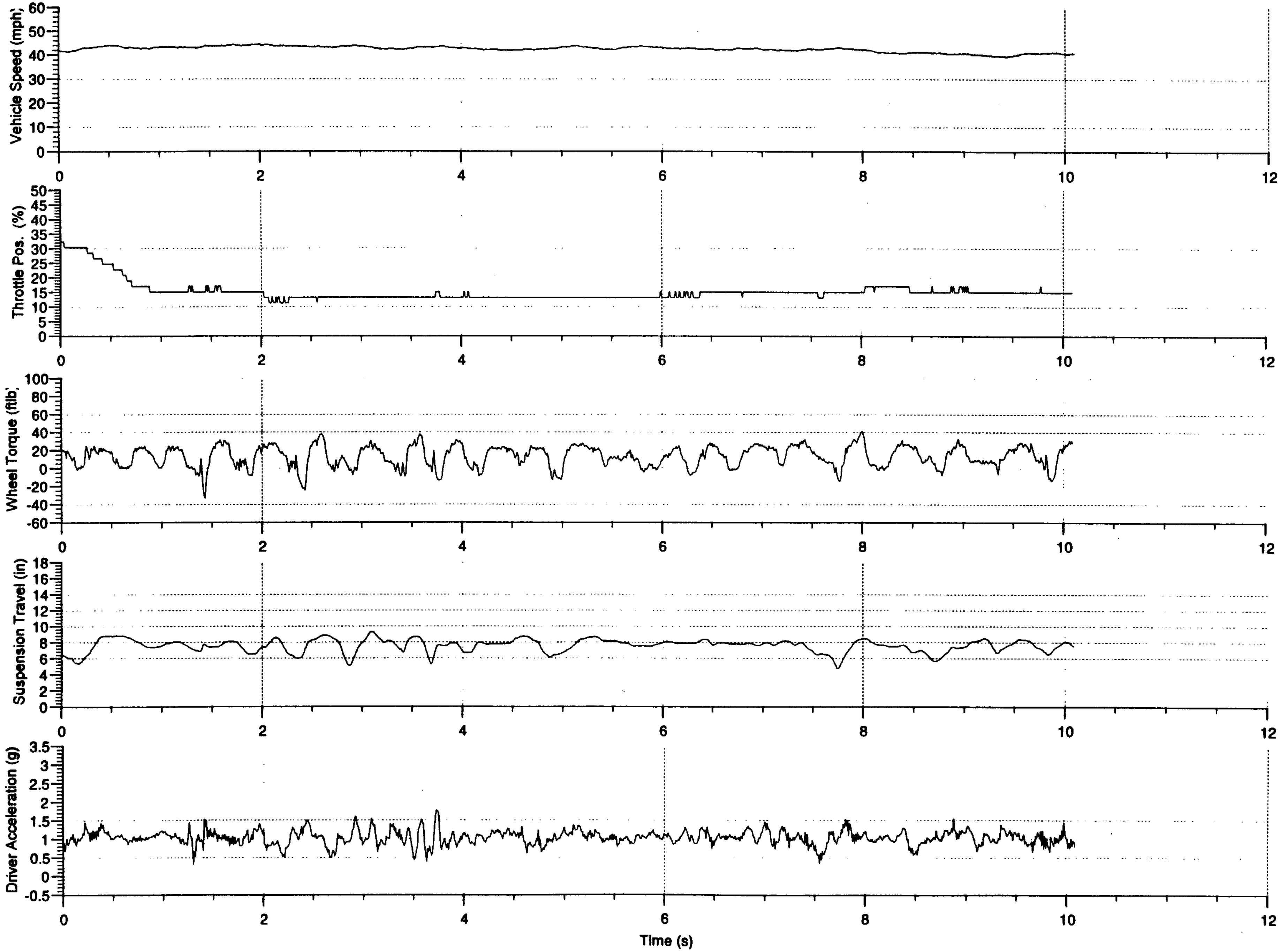
LOW RMS COURSE (0.576)

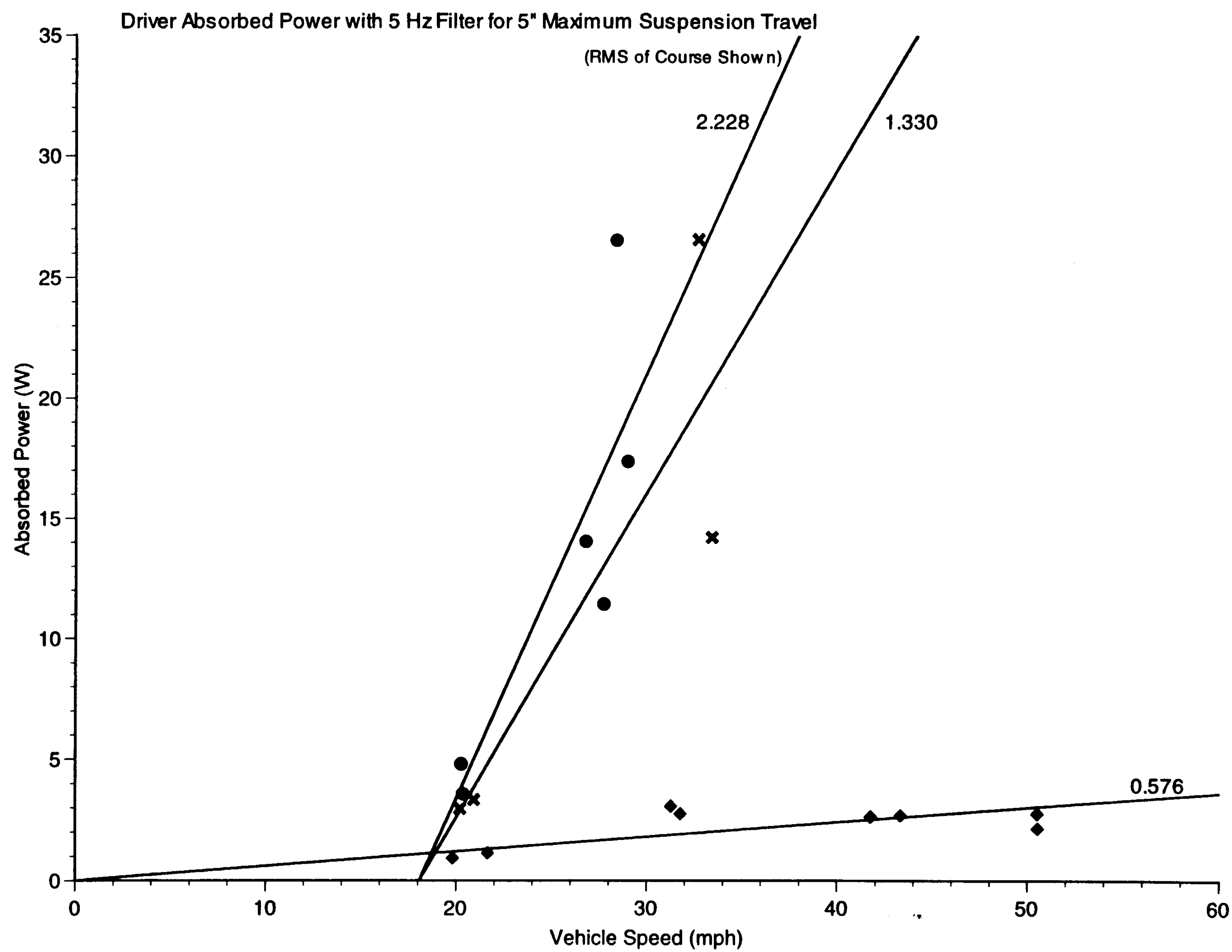
Time	Speed	Throttle Position	Accelero-meter	LF Wheel speed	LF Wheel torque	LF Sus Pos	RF Wheel speed	RF Wheel torque	RF Sus Pos	LR Wheel speed	LR Wheel torque	LR Sus Pos	RR Wheel speed	RR Wheel torque	RR Sus Pos
0.44	43.495	24.7	1.112	44.748	403.681	9.19	0.048	338.229	8.756	43.632	20.413	8.77	44.004	2.969	9.452
0.45	43.636	24.7	1.205	44.736	388.687	9.119	0	324.54	8.8	43.68	18.265	8.784	44.052	6.531	9.452
0.46	43.761	24.7	1.082	44.784	370.233	9.119	0	308.569	9.051	43.728	19.339	8.784	44.016	7.718	9.452
0.47	43.745	24.7	1.082	44.736	354.662	9.095	0.012	297.732	9.026	43.728	18.265	8.757	44.124	13.062	9.452
0.48	43.839	24.7	0.988	44.736	344.282	9.095	0.024	296.021	9.128	43.8	18.802	8.757	44.1	11.875	9.452
0.49	43.901	24.7	1.021	44.736	334.478	9	0.012	293.169	9.103	43.848	16.116	8.784	44.148	11.281	9.419
0.5	43.964	24.7	0.985	44.736	322.368	8.886	0	280.051	9.154	43.872	18.265	8.757	44.112	11.875	9.387
0.51	43.995	24.7	1.012	44.712	313.718	8.886	0	276.629	9.026	43.92	15.041	8.757	44.196	11.281	9.258
0.52	43.948	24.7	1.06	44.724	322.368	8.864	0.012	280.051	8.844	43.932	7.521	8.757	44.22	11.875	9.065
0.53	43.886	22.782	1.063	44.664	329.288	8.864	0	288.606	8.778	43.944	6.984	8.784	44.208	8.312	8.806
0.54	43.87	22.782	1.085	44.664	336.208	8.864	0.012	291.458	8.756	43.944	4.835	8.757	44.196	-5.816	8.701
0.55	43.792	22.782	1.097	44.64	340.822	8.864	0	297.732	8.667	43.92	10.744	8.811	44.256	-2.644	8.612
0.56	43.761	22.782	1.045	44.616	350.049	8.818	0	306.288	8.667	43.956	7.521	8.811	44.196	-2.115	8.507
0.57	43.745	22.782	1.057	44.604	359.853	8.705	0	311.992	8.667	43.944	2.686	8.811	44.268	-0.529	8.433
0.58	43.808	22.782	1.118	44.58	368.503	8.705	0	313.703	8.667	43.956	1.074	8.811	44.208	-6.345	8.418
0.59	43.792	22.782	1.073	44.604	376	8.705	0	315.414	8.622	43.968	0	8.811	44.22	-12.162	8.388
0.6	43.714	22.782	1.012	44.592	380.613	8.705	0.036	320.547	8.667	44.028	2.686	8.811	44.196	-16.92	8.388
0.61	43.62	22.782	0.997	44.592	385.227	8.682	0.012	334.806	8.6	44.052	0	8.811	44.196	-19.564	8.388
0.62	43.386	20.863	1.018	44.58	382.92	8.636	0.012	338.229	8.578	44.052	1.074	8.757	44.148	-29.611	8.418
0.63	43.245	20.863	0.973	44.616	375.423	8.636	0.012	329.103	8.444	44.076	0	8.73	44.196	-30.139	8.388
0.64	43.198	20.863	0.937	44.64	371.386	8.591	0.012	321.117	8.378	44.064	1.074	8.703	44.172	-33.312	8.418
0.65	43.073	20.863	0.846	44.652	369.656	8.523	0	321.117	8.178	44.076	-0.583	8.649	44.22	-33.312	8.388
0.66	43.026	18.945	0.961	44.664	357.546	8.5	0.024	311.992	8.111	44.088	2.149	8.595	44.196	-38.071	8.358
0.67	42.995	18.945	0.952	44.676	350.626	8.5	0.012	296.592	7.957	44.1	0	8.595	44.196	-34.37	8.299
0.68	43.073	18.945	0.961	44.688	346.012	8.5	0.012	283.473	7.913	44.088	3.223	8.541	44.16	-30.668	8.194
0.69	43.057	18.945	0.912	44.664	338.515	8.432	0.012	275.488	7.804	44.124	2.686	8.486	44.22	-20.093	8.149
0.7	43.167	18.945	1.057	44.7	327.558	8.5	0.012	260.088	7.761	44.04	4.298	8.405	44.196	-18.507	8.045
0.71	43.167	17.026	1.057	44.7	309.104	8.5	0	242.407	7.696	44.088	11.281	8.324	44.196	-9.518	7.926
0.72	43.073	17.026	0.931	44.712	299.877	8.5	0.012	233.281	7.652	44.088	17.727	8.27	44.196	-10.046	7.956
0.73	43.042	17.026	1.024	44.712	290.65	8.5	0.012	224.725	7.543	44.124	19.339	8.189	44.16	-7.931	7.912
0.74	42.979	17.026	0.931	44.736	283.153	8.523	0.012	221.873	7.587	44.124	22.562	8.135	44.172	-6.345	7.926
0.75	42.995	17.026	1.039	44.736	267.583	8.591	0	216.17	7.522	44.124	18.265	8.108	44.16	-8.989	7.897
0.76	42.964	17.026	0.955	44.736	260.086	8.591	0.012	207.044	7.587	44.16	22.562	8.054	44.172	-7.403	7.897
0.77	42.995	17.026	1.088	44.712	247.975	8.591	0	197.348	7.543	44.136	20.951	8	44.172	-8.989	7.897
0.78	42.948	17.026	0.931	44.736	247.399	8.636	0.012	193.355	7.63	44.136	23.637	8	44.172	-7.931	7.824
0.79	42.917	17.026	1.021	44.748	237.595	8.682	0.012	186.511	7.63	44.184	21.488	7.886	44.196	-2.644	7.765
0.8	42.776	17.026	0.979	44.748	232.981	8.682	0.012	177.385	7.739	44.172	23.637	7.771	44.196	-6.345	7.691
0.81	42.635	17.026	0.997	44.676	235.288	8.682	0	177.955	7.717	44.148	21.488	7.686	44.232	-7.931	7.574
0.82	42.62	17.026	0.964	44.664	237.595	8.705	0.012	177.385	7.761	44.124	22.562	7.6	44.244	-8.46	7.485
0.83	42.698	17.026	1.045	44.676	237.595	8.705	0.012	177.955	7.761	44.112	24.711	7.5	44.244	-8.989	7.397
0.84	42.823	17.026	1.003	44.676	239.902	8.864	0.012	177.385	7.761	44.136	20.413	7.457	44.244	-12.69	7.324
0.85	42.807	17.026	1.012	44.64	246.822	8.864	0	179.666	7.804	44.112	19.339	7.429	44.256	-9.518	7.279
0.86	42.698	17.026	1.051	44.64	244.515	8.886	0.012	178.525	7.913	44.136	19.876	7.371	44.268	-8.46	7.279

JTEV TESTING 11/26/96 **LOW RMS COURSE (0.576)**

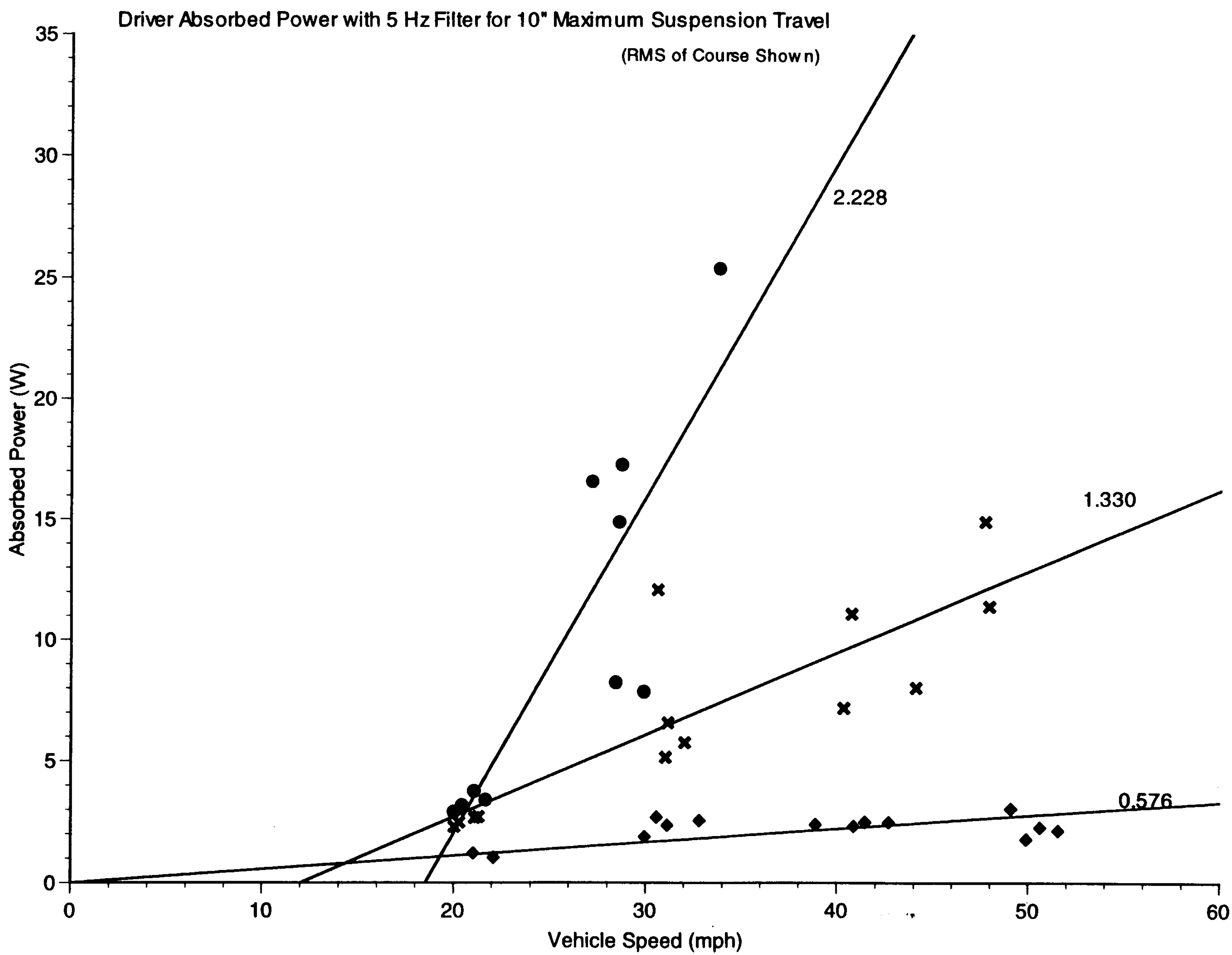
Time	Speed	Throttle Position	Accelero-meter	LF Wheel speed	LF Wheel torque	LF Sus Pos	RF Wheel speed	RF Wheel torque	RF Sus Pos	LR Wheel speed	LR Wheel torque	LR Sus Pos	RR Wheel speed	RR Wheel torque	RR Sus Pos
0.87	42.792	17.026	1.045	44.664	246.245	9	0	183.659	7.957	44.16	16.116	7.4	44.244	-8.989	7.265
0.88	42.698	17.026	1.051	44.676	244.515	9.048	0.012	192.214	8.022	44.16	18.265	7.371	44.244	-6.345	7.235
0.89	42.62	15.108	1.06	44.652	239.902	9.095	0	192.785	8	44.184	16.116	7.386	44.292	-4.759	7.279
0.9	42.604	15.108	1.085	44.688	232.981	9.095	0.036	188.222	8.044	44.22	15.041	7.371	44.256	-6.345	7.235
0.91	42.604	15.108	1.109	44.664	230.098	9.095	0.012	188.222	8.044	44.22	13.967	7.371	44.292	-8.989	7.265
0.92	42.76	15.108	1.027	44.688	228.368	9.095	0.048	187.081	8.133	44.232	11.818	7.4	44.292	-19.035	7.235
0.93	42.885	15.108	1.142	44.712	223.178	9.095	0	183.088	8.178	44.208	7.521	7.4	44.34	-29.082	7.279
0.94	42.964	15.108	1.142	44.7	221.448	9.119	0.012	173.962	8.289	44.232	6.446	7.429	44.34	-37.542	7.309
0.95	43.12	15.108	1.082	44.688	215.681	9.238	0	167.688	8.267	44.232	4.835	7.429	44.376	-42.83	7.368
0.96	43.198	15.108	1.148	44.736	214.527	9.286	0.012	161.414	8.378	44.232	2.686	7.429	44.364	-46.531	7.456
0.97	43.229	15.108	1.19	44.688	211.644	9.31	0	155.14	8.422	44.208	1.074	7.457	44.388	-50.232	7.544
0.98	43.198	15.108	1.196	44.712	204.147	9.429	0.048	147.725	8.467	44.256	1.074	7.486	44.352	-48.646	7.603
0.99	43.182	15.108	1.215	44.688	196.074	9.476	0	140.311	8.444	44.232	1.074	7.5	44.4	-39.128	7.647
1	43.214	15.108	1.154	44.736	188.577	9.476	0.012	136.318	8.467	44.256	1.074	7.543	44.388	-31.197	7.691
1.01	43.292	15.108	1.199	44.748	186.847	9.476	0	140.311	8.489	44.304	3.223	7.6	44.388	-30.139	7.75
1.02	43.339	15.108	1.196	44.772	179.35	9.476	0.024	135.177	8.6	44.328	5.372	7.671	44.388	-27.496	7.779
1.03	43.432	15.108	1.118	44.784	165.509	9.476	0	126.051	8.511	44.352	8.595	7.743	44.436	-17.978	7.838
1.04	43.448	15.108	1.133	44.831	163.779	9.476	0.036	123.77	8.489	44.34	13.967	7.786	44.436	-7.931	7.838
1.05	43.417	15.108	1.082	44.796	166.086	9.429	0.012	132.896	8.444	44.412	20.413	7.829	44.46	-2.644	7.838
1.06	43.37	15.108	1.1	44.807	167.239	9.31	0.012	134.037	8.489	44.412	20.413	7.886	44.508	-7.403	7.853
1.07	43.354	15.108	1.094	44.819	166.662	9.31	0	131.755	8.422	44.352	24.711	7.886	44.508	-8.989	7.853
1.08	43.354	15.108	0.997	44.784	170.699	9.31	0.012	131.755	8.4	44.424	22.562	7.886	44.532	-7.931	7.897
1.09	43.401	15.108	1.057	44.784	177.043	9.286	0.012	139.17	8.311	44.448	18.265	7.914	44.532	-3.173	7.926
1.1	43.323	15.108	1.051	44.807	177.043	9.286	0.024	144.303	8.311	44.448	23.099	7.943	44.556	2.375	8
1.11	43.292	15.108	1.048	44.807	178.773	9.286	0	148.866	8.244	44.472	24.711	8	44.544	6.531	8.06
1.12	43.354	15.108	1.148	44.784	177.043	9.19	0	153.429	8.244	44.448	19.876	8.029	44.58	10.687	8.149
1.13	43.245	15.108	1.057	44.784	177.62	9.095	0.012	164.837	8.178	44.52	20.413	8	44.628	11.281	8.179
1.14	43.292	15.108	1.027	44.807	182.233	9	0.036	172.822	8.244	44.496	22.562	8.027	44.58	14.249	8.194
1.15	43.229	15.108	1.009	44.831	173.006	8.864	0.012	172.251	8.244	44.556	23.099	8.027	44.604	16.031	8.269
1.16	43.136	15.108	1.048	44.831	167.239	8.795	0.012	167.688	8.222	44.592	23.637	8.054	44.604	13.062	8.194
1.17	43.104	15.108	0.9	44.831	170.699	8.705	0	169.97	8.089	44.604	20.413	8	44.628	15.437	8.269
1.18	43.104	15.108	0.873	44.784	166.662	8.705	0.024	167.118	8.044	44.628	19.339	8.014	44.628	11.875	8.194
1.19	43.057	15.108	0.979	44.807	156.282	8.705	0	164.266	7.935	44.592	20.413	7.971	44.652	13.656	8.209
1.2	43.229	15.108	0.961	44.796	151.669	8.682	0	160.274	8.022	44.604	20.951	7.886	44.652	11.875	8.164
1.21	43.354	15.108	0.84	44.772	149.362	8.591	0.012	156.281	8	44.592	17.19	7.829	44.664	13.062	8.09
1.22	43.261	15.108	0.888	44.784	145.325	8.5	0.012	145.444	8.044	44.568	13.967	7.714	44.676	11.875	8
1.23	43.229	15.108	0.9	44.736	166.086	8.5	0	132.896	8	44.544	9.67	7.657	44.64	13.062	7.853
1.24	43.229	15.108	0.822	44.736	160.319	8.682	0	127.763	8.044	44.568	6.446	7.6	44.676	11.875	7.779
1.25	43.245	15.108	1.097	44.748	43.828	8.886	0.012	116.926	8.044	44.532	1.074	7.543	44.652	10.093	7.721
1.26	43.229	15.108	1.423	44.748	-13.033	9.286	0	108.94	8.044	44.58	3.223	7.486	44.628	9.5	7.706
1.27	43.167	15.108	1.06	44.7	-80.915	9.119	0.012	139.17	8.089	44.58	0	7.4	44.628	11.281	7.662
1.28	43.104	17.026	1.051	44.724	-17.378	8.864	0	152.288	8.2	44.52	0.537	7.314	44.544	7.718	7.603
1.29	43.104	17.026	0.855	44.712	1.153	8.636	0.012	160.274	8.178	44.556	1.074	7.229	44.544	8.906	7.603

JTEV TESTING 11/26/96 LOW RMS (.576) COURSE

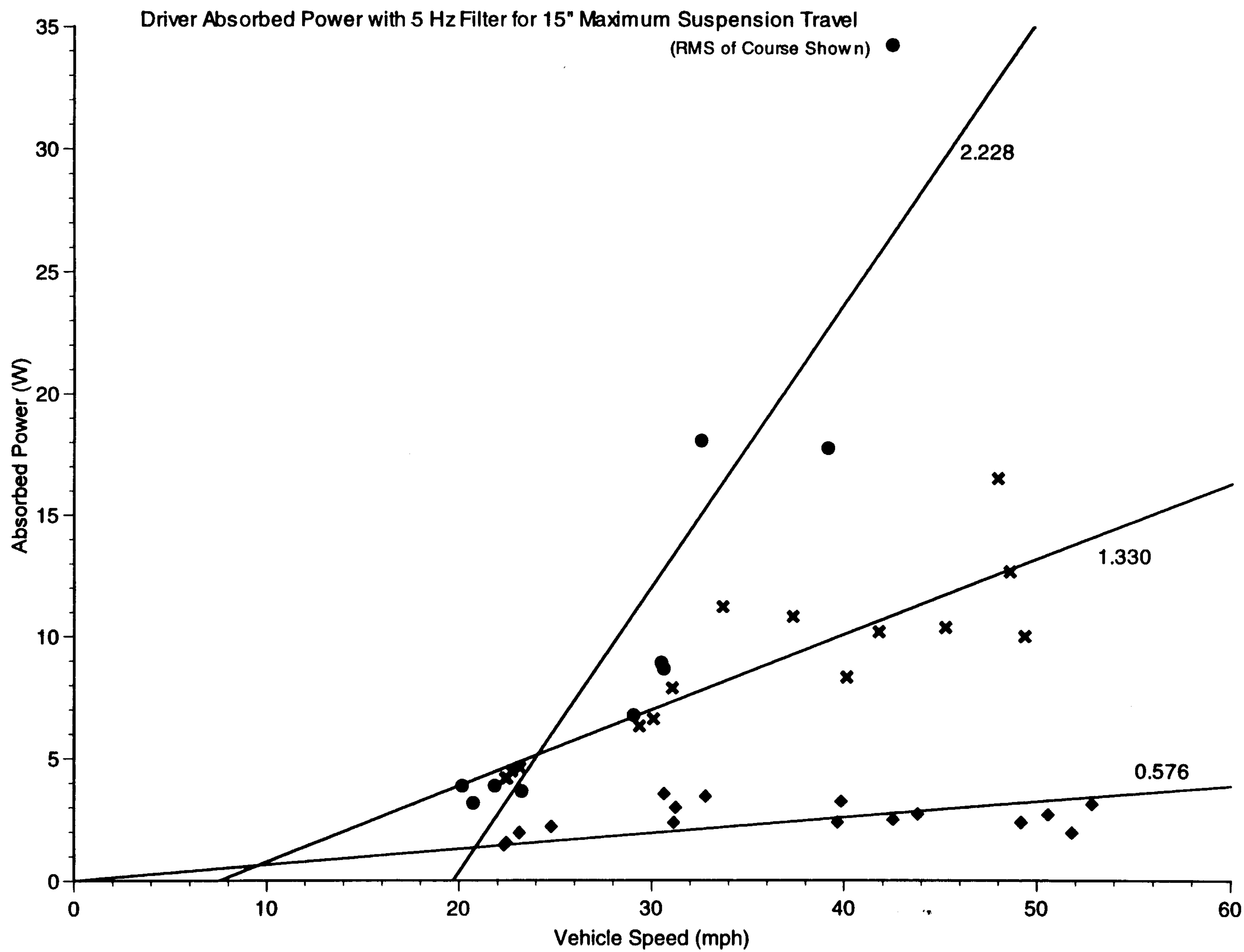




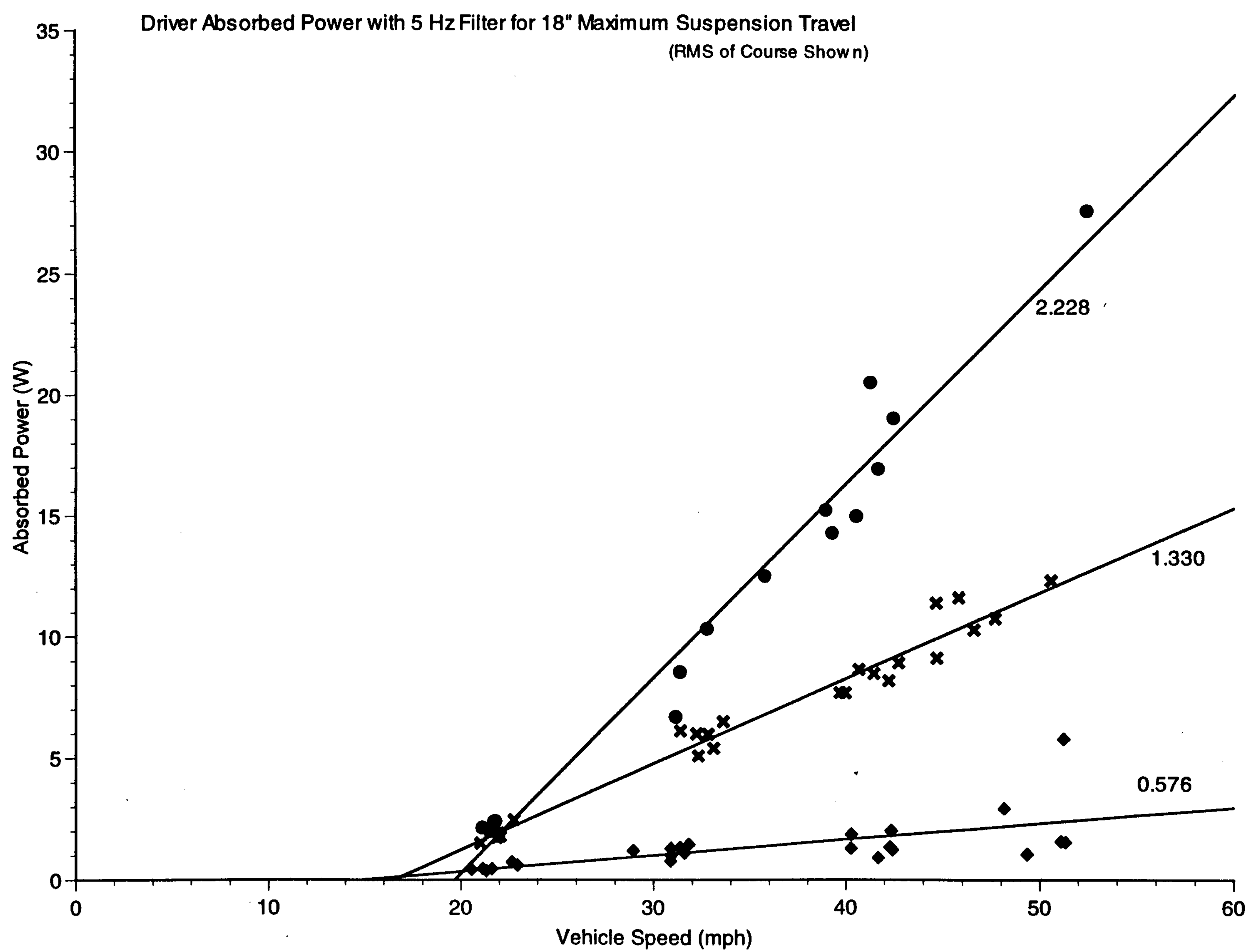
Driver Absorbed Power with 5 Hz Filter for 5" Maximum Suspension Travel
(RMS of Course Shown)
2.228
1.330
0.576
Absorbed Power (W)
0
5
10
15
20
25
30
35
Vehicle Speed (mph)
0
10
20
30
40
50
60



Driver Absorbed Power with 5 Hz Filter for 10" Maximum Suspension Travel
(RMS of Course Shown)
2.228
1.330
0.576
Absorbed Power (W)
Vehicle Speed (mph)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60

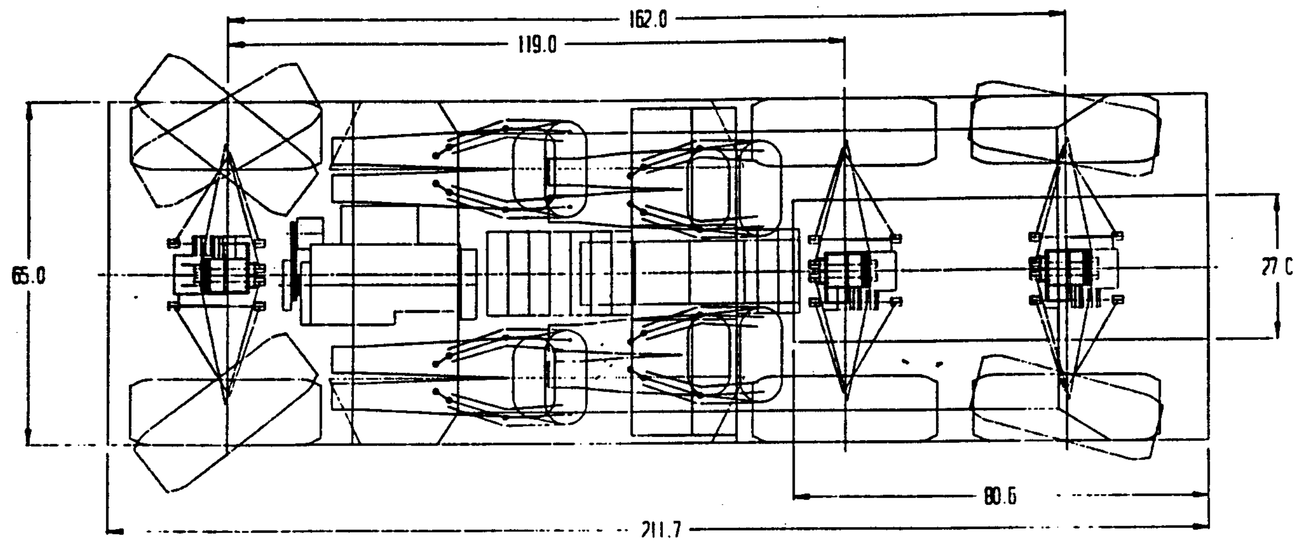


Driver Absorbed Power with 5 Hz Filter for 15" Maximum Suspension Travel
(RMS of Course Shown)
2.228
1.330
0.576
Absorbed Power (W)
Vehicle Speed (mph)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60

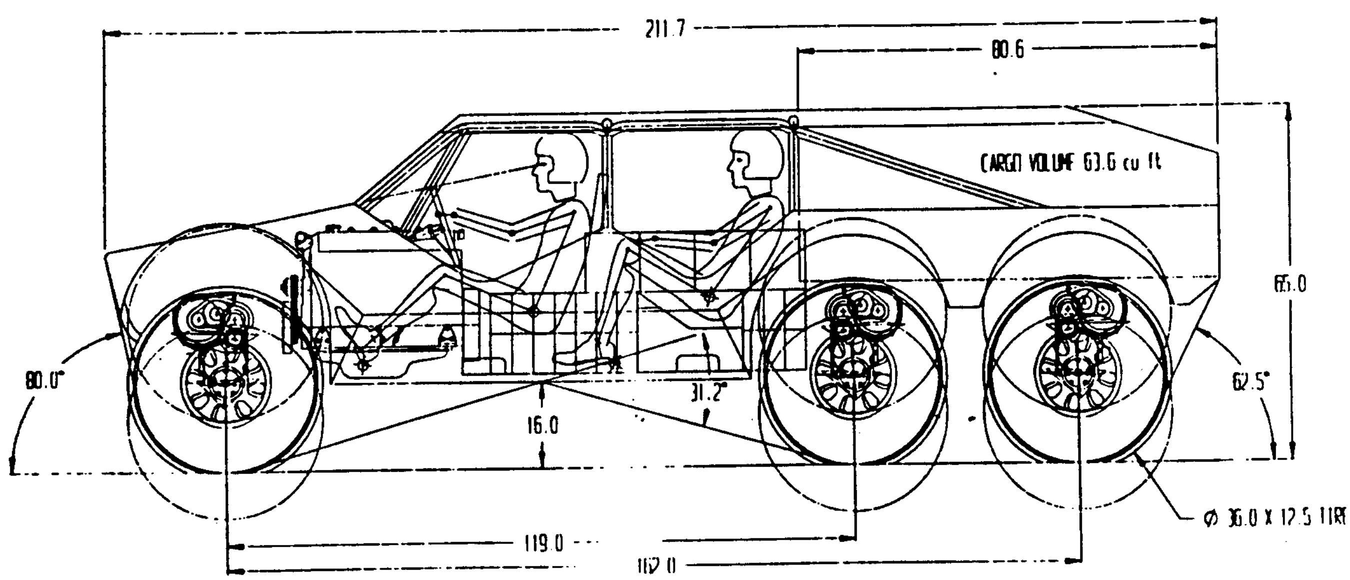

Driver Absorbed Power with 5 Hz Filter for 18" Maximum Suspension Travel
(RMS of Course Shown)
Absorbed Power (W)
35
30
25
20
15
10
5
0
Vehicle Speed (mph)
0
10
20
30
40
50
60
2.228
1.330
0.576

Appendix C Notional Vehicle Examples

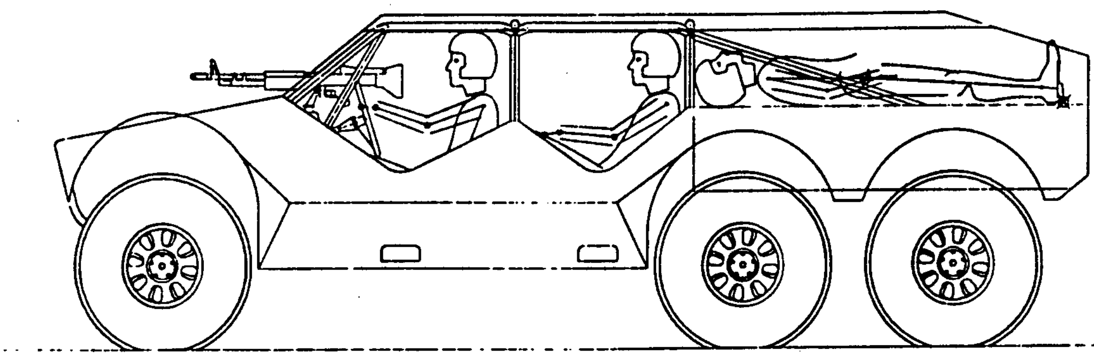
Six Wheel Top View

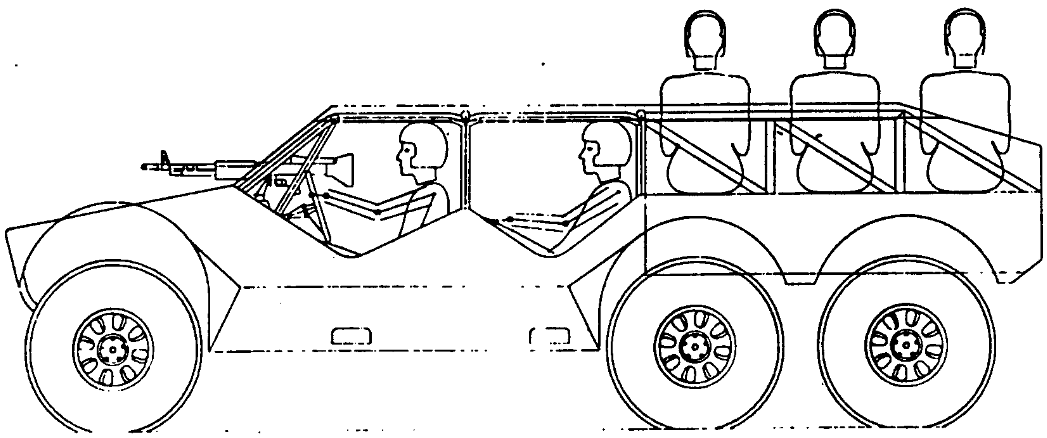


Six Wheel Layout: Side View

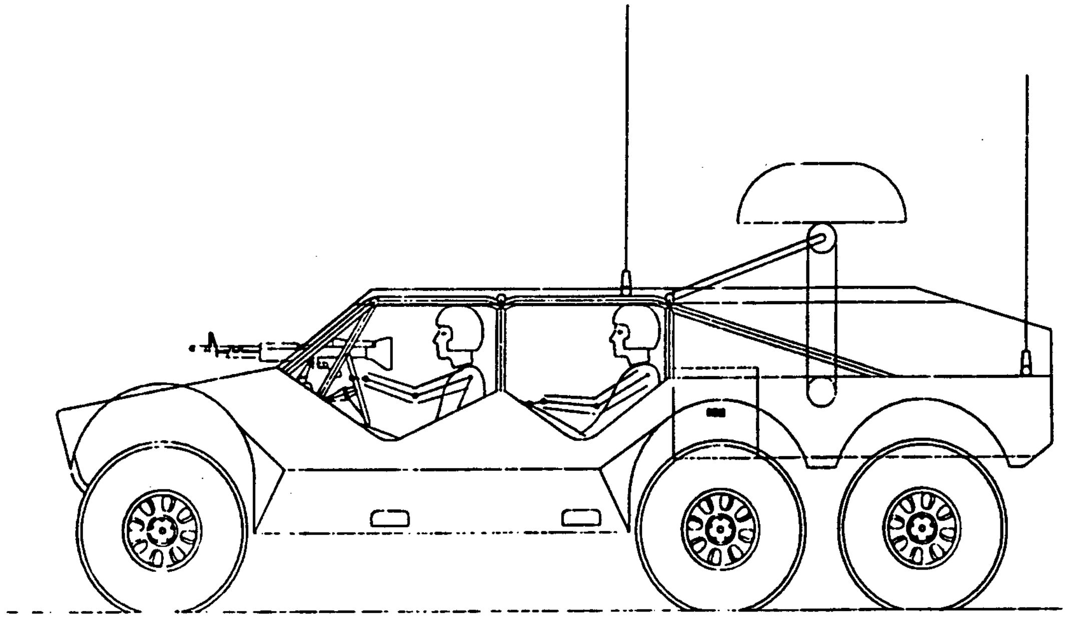


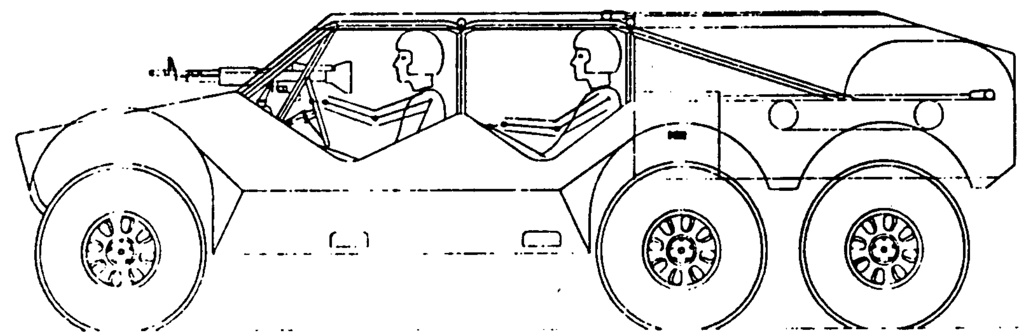
MISSION PROFILE - 6 WHEEL PERSONNEL/LITTER CARRIER





MISSION PROFILE - 6 WHEEL SENSOR CARRIEF





Appendix D Weight and Volume Data

	ITEM WEIGHT	NUMBER	TOTAL WEIGHT	LENGTH	HEIGHT	WIDTH	VOLUME PER ITEM	TOTAL VOLUME	
RSTA-V WEIGHT AND VOLUME STUDY									
VEHICLE, BASIC LOAD LIST									
ALL WEIGHTS ARE NATO AVERAGES									
1. CREW AND PERSONAL EQUIFMENT									
a NATO average crewman	176	2	352	N/A	N/A	N/A	N/A	N/A	
b Personal weapon rifle	8	2	16	39.25	9	2.5	883.1 cu in	1766.3 cu in	
c Weapon cleaning kit	0.8	2	1.6	N/A	N/A	N/A	N/A	N/A	
d Ammunition (5x30 round mag's)	5	2	10	7.25	0.875	2.5	15.9 cu in	31.7 cu in	
e Ruck sack with standard field gear	65	2	130	26	14	24	8736.0 cu in	17472.0 cu in	
			509.6				9835.0 cu in	19270.0 cu in	
2. MAIN MOUNT WEAPON AND AMMUNITION									
a Standard Browning .50 cal MG	85	1	85	65.5	9	7.5	4421.3 cu in	4421.3 cu in	
b Night sight	11	1	11	16	7.25	6.5	786.9 cu in	786.9 cu in	
c Spare barrel w/case	24	1	24	45	2.25	2.25	227.8 cu in	227.8 cu in	
d Main weapon cleaning kit	3	1	3	N/A	N/A	N/A	N/A	N/A	
e Ammunition (100 rd cans)	37	5	185	13.5	9	7.75	941.6 cu in	4708.1 cu in	
f Vehicle soft mount	70	1	70	5	1	3.25	16.3 cu in	16.3 cu in	
		1		5	1	3.25	16.3 cu in	16.3 cu in	
		1		15.5	2.75	6.75	287.7 cu in	287.7 cu in	
			378				6617.8 cu in	10384.3 cu in	
3. WATER, RATIONS, PETROLEUM PRODUCTS									
a Combat ration 1 MRE	1	6	6	8.5	2	4.75	80.8 cu in	484.5 cu in	
b Hexamine stove	0.5	2	1	4.75	1.25	3.75	22.3 cu in	44.5 cu in	
		1		3.75	0.75	2.5	7.0 cu in	7.0 cu in	
c Water 5 gallons	35	1	35	13.75	19	7	1828.8 cu in	1828.8 cu in	
d Fuel 1 gallon	21	6.5	136.5	13.75	18.25	6.5	1631.1 cu in	10602.1 cu in	
e Oils motor 1 quart	2.75	4	11	4	9	2.5	90.0 cu in	360.0 cu in	
f other lubricants 1 quart	2.75	4	11	4	9	2.5	90.0 cu in	360.0 cu in	
			200.5				3749.9 cu in	13686.9 cu in	
4. COMMUNICATIONS EQUIPMENT									
a VHF radio (Vehicle mount complete)	75.5	1	75.5	11	3.5	10.25	394.6 cu in	394.6 cu in	radio
		1		11	3.5	10.25	394.6 cu in	394.6 cu in	radio
		1		15.5	7.75	14.75	1771.8 cu in	1771.8 cu in	radio mount
		1		16.75	5	13.5	1130.6 cu in	1130.6 cu in	radio mount bracket
		1		11.25	3.75	5.75	242.6 cu in	242.6 cu in	amplifier
b Vehicle Communication and intercom box 2/cable	16.5	1	16.5	6	3.75	4	90.0 cu in	90.0 cu in	
c Crew helmets compatible w/above	3.75	2	7.5	10	9	8	720.0 cu in	1440.0 cu in	
			99.5				4744.3 cu in	5464.3 cu in	
5. VEHICLE ON BOARD BASIC EQUIPMENT (OSE)									
a Spare tire/wheel combination	65	1	65	36	12.5	16.5	7425.0 cu in	7425.0 cu in	
b Jacking device	33	1	33	18	4.25	4.5	344.3 cu in	344.3 cu in	jack
		1		19	2.5	13	617.5 cu in	617.5 cu in	tools
c Tow strap	4	1	4	3.5	1	1.75	6.1 cu in	6.1 cu in	
d Shovel	3	1	3	47	2.5	18	2115.0 cu in	2115.0 cu in	
e Axe	5.5	1	5.5	36	8	2.5	720.0 cu in	720.0 cu in	
f Vehicle tools w/bag	25	1	25	18	4	4	288.0 cu in	288.0 cu in	
g Spare parts pack	25	1	25	36	12	12	5184.0 cu in	5184.0 cu in	
h First extinguisher and mount	6.5	1	6.5	5.5	5	16.25	446.9 cu in	446.9 cu in	
i First aid kit	1.5	1	1.5	11	7.5	10.75	886.9 cu in	886.9 cu in	
j Camouflage net w/support system	50	1	50	45	8	25	9000.0 cu in	9000.0 cu in	net
		1		49	12	12	7056.0 cu in	7056.0 cu in	supports
			218.5				34089.6 cu in	34089.6 cu in	Total per category
			1406.1				31803.0 cu in	55861.5 cu in	Totals

RSTV 4x4 Weight Distribution

Vehicle Dimensions											
Length	168.7	in.									
Width	65.0	in.									
Height	66.0	in.								pitch axis	
Wheelbase	119.0	in.								moment of inertia	
	FRONT	WIDE	HEIGHT								
	Xcg	Ycg	Zcg	Weight		W*X	W*Y	W*Z		Pitch rad	mom of ine
Powertrain											
Engine	46.8	0.0	24.5	750.0		35100	0	18375		58.24196	2544094
Transmission	10.0	0.0	24.5	260.0		2600	0	6370		21.94112	125167.4
Transfer Case	-15.0	0.0	24.5	225.0		-3375	0	5512.5		7.001898	11030.98
Front Diff	60.0	0.0	23.0	150.0		9000	0	3450		71.52605	767396.5
Rear Diff	-58.0	0.0	23.0	150.0		-8700	0	3450		47.42481	337366.9
Fuel Cells	-31.1	0.0	18.2	45.0		-1399.5	0	819		23.35896	24553.85
pumps and lines	-22.0	-17.0	21.0	16.0		-352	-272	336		14.3226	3282.19
Exhaust/Muffler	-8.0	-7.5	17.6	36.0		-288	-270	633.6		13.12983	6206.125
Radiator	74.0	0.0	24.2	65.0		4810	0	1573		85.36932	473714.8
Fan	78.0	0.0	0.0	0.0		0	0	0		94.1714	0
Intercooler	0.0	0.0	0.0	0.0		0	0	0		32.32967	0
Battery pack	0.0	0.0	18.13	120.0		0	0	2175.6		16.5386	32823.02
Drivetrain										32.32967	0
LF HALFSHAFT	59.5	16.25	16.0	20.0		1190	325	320		72.08978	103938.7
RF HALFSHAFT	59.5	-16.25	16.0	20.0		1190	-325	320		72.08978	103938.7
LR HALFSHAFT	-102.5	16.25	16.0	20.0		-2050	325	320		92.47201	171021.4
RR HALFSHAFT	-102.5	-16.25	16.0	20.0		-2050	-325	320		92.47201	171021.4
Shifter	4.0	-4.0	32.6	8.0		32	-32	260.8		15.31437	1876.24
Throttle	32.9	-17.0	30.8	2.0		65.8	-34	61.6		44.05006	3880.815
Brake	32.9	-17.0	30.8	6.0		197.4	-102	184.8		44.05006	11642.45
Hand brake	-8.0	2.0	32.6	2.5		-20	5	81.5		3.870984	37.4613
Suspension										32.32967	0
Tires/Wheels LF	59.5	26.0	15.15	72.0		4284	1872	1090.8		72.26374	375987.5
RF	59.5	-26.0	15.15	72.0		4284	-1872	1090.8		72.26374	375987.5
LR	-102.5	26.0	15.15	72.0		-7380	1872	1090.8		92.60769	617485.3
RR	-102.5	-26.0	15.15	72.0		-7380	-1872	1090.8		92.60769	617485.3
Upright LF	59.5	26.0	15.15	14.0		833	364	212.1		72.26374	73108.67
RF	59.5	-26.0	15.15	14.0		833	-364	212.1		72.26374	73108.67
LR	-102.5	26.0	15.15	14.0		-1435	364	212.1		92.60769	120066.6
RR	-102.5	-26.0	15.15	14.0		-1435	-364	212.1		92.60769	120066.6
Rotor	59.5	26.0	15.15	10.0		595	260	151.5		72.26374	52220.48
RF	59.5	-26.0	15.15	10.0		595	-260	151.5		72.26374	52220.48
LR	-102.5	26.0	15.15	10.0		-1025	260	151.5		92.60769	85761.84
RR	-102.5	-26.0	15.15	10.0		-1025	-260	151.5		92.60769	85761.84
Caliper	59.5	26.0	15.15	7.0		416.5	182	106.05		72.26374	36554.34
RF	59.5	-26.0	15.15	7.0		416.5	-182	106.05		72.26374	36554.34
LR	-102.5	26.0	15.15	7.0		-717.5	182	106.05		92.60769	60033.29
RR	-102.5	-26.0	15.15	7.0		-717.5	-182	106.05		92.60769	60033.29
Upper A-arm	59.5	16.25	21.2	13.0		773.5	211.25	275.6		71.2374	65971.98
RF	59.5	-16.25	21.2	13.0		773.5	-211.25	275.6		71.2374	65971.98
LR	-102.5	16.25	11.6	18.0		-1845	292.5	208.8		93.25602	156540.3
RR	-102.5	-16.25	11.6	18.0		-1845	-292.5	208.8		93.25602	156540.3
Lower A-arm	59.5	16.25	11.6	19.0		1130.5	308.75	220.4		73.09274	101508.4
RF	59.5	-16.25	11.6	19.0		1130.5	-308.75	220.4		73.09274	101508.4
LR	-102.5	16.25	11.6	18.0		-1845	292.5	208.8		93.25602	156540.3
RR	-102.5	-16.25	11.6	18.0		-1845	-292.5	208.8		93.25602	156540.3
Shocks	59.5	16.25	27.0	23.5		1398.25	381.875	634.5		70.72696	117554.1
RF	59.5	-16.25	27.0	23.5		1398.25	-381.875	634.5		70.72696	117554.1
LR	-102.5	16.25	40.0	23.5		-2408.75	381.875	940		91.86087	198302.9
RR	-102.5	-16.25	40.0	23.5		-2408.75	-381.875	940		91.86087	198302.9
Springs	59.5	16.25	27.0	20.0		1190	325	540		70.72696	100046.1
RF	59.5	-16.25	27.0	20.0		1190	-325	540		70.72696	100046.1
LR	-102.5	16.25	40.0	20.0		-2050	325	800		91.86087	168768.4
RR	-102.5	-16.25	40.0	20.0		-2050	-325	800		91.86087	168768.4
Ride Ht. Adjuster	59.5	16.25	40.0	10.0		595	162.5	400		71.30416	50842.83
RF	59.5	-16.25	40.0	10.0		595	-162.5	400		71.30416	50842.83
LR	-102.5	16.25	40.0	10.0		-1025	162.5	400		91.86087	84384.2
RR	-102.5	-16.25	40.0	10.0		-1025	-162.5	400		91.86087	84384.2
Rockers LR	-45.0	16.25	33.0	14.0		-630	227.5	462		33.95608	16142.21
RR	-45.0	-16.25	33.0	14.0		-630	-227.5	462		33.95608	16142.21
Steering										32.32967	0
Box	56.0	-6.0	18.0	26.0		1456	-156	468		68.27345	121192.9
Rockers/Links	50.7	-8.1	19.5	20.0		1014	-162	390		62.7917	78855.94
Shaft	23.1	-17.0	34.0	3.5		80.85	-59.5	119		34.44201	4151.881
Wheel	10.0	-17.0	38.8	3.3		33	-56.1	128.04		22.77456	1711.647
Chassis										32.32967	0

Frame	-16.0	0.0	30.0	500.0	-8000	0	15000	4.86466	11832.46
Bumper	77.8	0.0	26.2	50.0	3890	0	1310	89.04434	396444.8
Body								32.32967	0
Panels/Covers/Dash	0.0	0.0	30.0	100.0	0	0	3000	11.15312	12439.22
Seats	0.0	0.0	40.0	46.0	0	0	1840	14.74631	10002.87
Mounts	0.0	0.0	13.15	26.0	0	0	341.9	20.49405	10920.16
Rear Deck	-55.1	0.0	29.5	34.4	-1895.44	0	1014.8	43.96043	66478.67
Wheel Arches	59.5	22.0	30.0	11.0	654.5	242	330	70.64858	54903.44
RF	59.5	-22.0	30.0	11.0	654.5	-242	330	70.64858	54903.44
LR	-102.5	22.0	30.0	11.0	-1127.5	242	330	91.35293	91798.94
RR	-102.5	-22.0	30.0	11.0	-1127.5	-242	330	91.35293	91798.94
Skid Plate	0.0	0.0	12.0	80.0	0	0	960	21.46815	36870.53
Windshield	26.2	0.0	52.9	33.0	864.6	0	1745.7	43.62905	62815.29
Electrical Harness	0.0	0.0	25.0	90.0	0	0	2250	12.36372	13757.53
Plumbing	0.0	0.0	25.0	20.0	0	0	500	12.36372	3057.229
Nuts & Bolts	0.0	0.0	25.0	50.0	0	0	1250	12.36372	7643.073
Fluids								32.32967	0
Fuel	-31.1	0.8	18.2	240.0	-7464	192	4368	23.35896	130953.9
Oil	11.5	0.8	15.6	20.0	230	16	312	27.02575	14607.83
Water	74.0	0.0	24.2	26.0	1924	0	629.2	85.36932	189485.9
		Weight Subtotal		4117.7				32.32967	4303852
Accessories								32.32967	0
Driver	0.0	17.0	30.5	255.0	0	4335	7777.5	11.14878	31695.29
Navigator	0.0	-17.0	30.5	255.0	0	-4335	7777.5	11.14878	31695.29
Passenger	-35.0	17.0	30.5	255.0	-8925	4335	7777.5	23.85276	145083.4
Passenger	-35.0	-17.0	30.5	0.0	0	0	0	23.85276	0
Payload	-50.0	0.0	40.0	1235.0	-61750	0	49400	40.0335	1979311
50 cal. Gun	-28.0	0.0	70.0	378.0	-10584	0	26460	43.08556	701706.1
		Total Weight		6495.7	-72412.3	3404.4	197124.5	I pitch	18828602
	X	Y	Z						
	-11.15	0.52	30.35					Rpitch	53.83889
Center of Gravity	70.65	0.52	30.35					Radius of Gyration	
Weight Distribution on Front		41							

RST-V 6x6 Parallel Hybrid Weight Distribution											
Vehicle Dimensions											
Length	211.7	in.									
Width	65.0	in.									
Height	66.0	in.								pitch axis	
Wheelbase	119.0	in.								moment of inertia	
Rear Wheelbase	162.0	in.									
	FRONT	WIDE	HEIGHT								
	Xcg	Ycg	Zcg	Weight		W*X	W*Y	W*Z		Pitch rad	mom of ine
Powertrain											
Engine	46.8	0.0	24.5	551.0		25786.8	0	13499.5		65.48546	2362879
alternator	20.0	0.0	24.5	85.0		1700	0	2082.5		38.73761	127551.2
Front Diff	65.9	0.0	23.0	120.0		7908	0	2760		84.63742	859619.2
Middle diff	-50.5	0.0	23.0	120.0		-6060	0	2760		32.22562	124618.9
Rear Diff	-93.5	0.0	23.0	120.0		-11220	0	2760		75.03345	675602.2
Transmission	0.0	20.0	24.5	260.0		0	5200	6370		18.87316	92611.02
Transfer case	-10.0	0.0	24.5	200.0		-2000	0	4900		9.164785	16798.66
Drive inverter	-10.0	0.0	35.0	75.0		-750	0	2625		11.32725	9622.988
alternator inverter	-10.0	-20.0	35.0	75.0		-750	-1500	2625		11.32725	9622.988
Fuel Cells	-31.1	0.0	18.2	45.0		-1399.5	0	819		15.6559	11029.82
pumps and lines	-22.0	-17.0	21.0	16.0		-352	-272	336		7.45511	889.2585
Exhaust/Muffler	-8.0	-7.5	17.6	36.0		-288	-270	633.6		14.60732	7681.455
Radiator	74.0	0.0	24.2	45.0		3330	0	1089		92.67401	386481.2
Fan	78.0	0.0	0.0	0.0		0	0	0		100.4862	0
Intercooler	0.0	0.0	0.0	0.0		0	0	0		33.32115	0
Battery pack	0.0	0.0	18.13	1260.0		0	0	22843.8		20.89916	550336.2
Drivetrain										33.32115	0
LF HALFSHAFT	59.5	16.25	16.0	12.0		714	195	192		78.97266	74840.17
RF HALFSHAFT	59.5	-16.25	16.0	12.0		714	-195	192		78.97266	74840.17
LM HALFSHAFT	-59.5	16.25	16.0	12.0		-714	195	192		42.5143	21689.59
RM HALFSHAFT	-59.5	-16.25	16.0	12.0		-714	-195	192		42.5143	21689.59
LR HALFSHAFT	-102.5	16.25	16.0	12.0		-1230	195	192		84.69353	86075.92
RR HALFSHAFT	-102.5	-16.25	16.0	12.0		-1230	-195	192		84.69353	86075.92
Shifter	4.0	-4.0	32.6	8.0		32	-32	260.8		23.14783	4286.575
Throttle	32.9	-17.0	30.8	2.0		65.8	-34	61.6		51.60699	5326.564
Brake	32.9	-17.0	30.8	6.0		197.4	-102	184.8		51.60699	15979.69
Hand brake	-8.0	2.0	32.6	2.5		-20	5	81.5		11.71232	342.9459
Suspension										33.32115	0
Tires/Wheels LF	59.5	26.0	15.15	72.0		4284	1872	1090.8		79.10241	450517.8
RF	59.5	-26.0	15.15	72.0		4284	-1872	1090.8		79.10241	450517.8
LM	-59.5	26.0	15.15	72.0		-4284	1872	1090.8		42.75484	131614.3
RM	-59.5	-26.0	15.15	72.0		-4284	-1872	1090.8		42.75484	131614.3
LR	-102.5	26.0	15.15	72.0		-7380	1872	1090.8		84.81452	517932.3
RR	-102.5	-26.0	15.15	72.0		-7380	-1872	1090.8		84.81452	517932.3
Upright LF	59.5	26.0	15.15	14.0		833	364	212.1		79.10241	87600.68
RF	59.5	-26.0	15.15	14.0		833	-364	212.1		79.10241	87600.68
LM	-59.5	26.0	15.15	14.0		-833	364	212.1		42.75484	25591.67
RM	-59.5	-26.0	15.15	14.0		-833	-364	212.1		42.75484	25591.67
LR	-102.5	26.0	15.15	14.0		-1435	364	212.1		84.81452	100709
RR	-102.5	-26.0	15.15	14.0		-1435	-364	212.1		84.81452	100709
Rotor	59.5	26.0	15.15	10.0		595	260	151.5		79.10241	62571.91
RF	59.5	-26.0	15.15	10.0		595	-260	151.5		79.10241	62571.91
LM	-59.5	26.0	15.15	10.0		-595	260	151.5		42.75484	18279.76
RM	-59.5	-26.0	15.15	10.0		-595	-260	151.5		42.75484	18279.76
LR	-102.5	26.0	15.15	10.0		-1025	260	151.5		84.81452	71935.04
RR	-102.5	-26.0	15.15	10.0		-1025	-260	151.5		84.81452	71935.04
Caliper	59.5	26.0	15.15	7.0		416.5	182	106.05		79.10241	43800.34
RF	59.5	-26.0	15.15	7.0		416.5	-182	106.05		79.10241	43800.34
LM	-59.5	26.0	15.15	7.0		-416.5	182	106.05		42.75484	12795.83
RM	-59.5	-26.0	15.15	7.0		-416.5	-182	106.05		42.75484	12795.83
LR	-102.5	26.0	15.15	7.0		-717.5	182	106.05		84.81452	50354.52
RR	-102.5	-26.0	15.15	7.0		-717.5	-182	106.05		84.81452	50354.52
Upper A-arm	59.5	16.25	21.2	13.0		773.5	211.25	275.6		78.37517	79854.67
RF	59.5	-16.25	21.2	13.0		773.5	-211.25	275.6		78.37517	79854.67
LM	-59.5	16.25	11.6	18.0		-1071	292.5	208.8		43.9233	34726.62
RM	-59.5	-16.25	11.6	18.0		-1071	-292.5	208.8		43.9233	34726.62
LR	-102.5	16.25	11.6	18.0		-1845	292.5	208.8		85.40951	131306.1
RR	-102.5	-16.25	11.6	18.0		-1845	-292.5	208.8		85.40951	131306.1
Lower A-arm	59.5	16.25	11.6	19.0		1130.5	308.75	220.4		79.74003	120811
RF	59.5	-16.25	11.6	19.0		1130.5	-308.75	220.4		79.74003	120811
LM	-59.5	16.25	11.6	18.0		-1071	292.5	208.8		43.9233	34726.62
RM	-59.5	-16.25	11.6	18.0		-1071	-292.5	208.8		43.9233	34726.62
LR	-102.5	16.25	11.6	18.0		-1845	292.5	208.8		85.40951	131306.1
RR	-102.5	-16.25	11.6	18.0		-1845	-292.5	208.8		85.40951	131306.1
Shocks	59.5	16.25	27.0	23.5		1398.25	381.875	634.5		78.11277	143387.7
RF	59.5	-16.25	27.0	23.5		1398.25	-381.875	634.5		78.11277	143387.7

LM	-59.5	16.25	40.0	23.5	-1398.25	381.875	940	42.71713	42881.7
RM	-59.5	-16.25	40.0	23.5	-1398.25	-381.875	940	42.71713	42881.7
LR	-102.5	16.25	40.0	23.5	-2408.75	381.875	940	84.79552	168971.6
RR	-102.5	-16.25	40.0	23.5	-2408.75	-381.875	940	84.79552	168971.6
Springs	59.5	16.25	27.0	20.0	1190	325	540	78.11277	122032.1
RF	59.5	-16.25	27.0	20.0	1190	-325	540	78.11277	122032.1
LM	-59.5	16.25	40.0	20.0	-1190	325	800	42.71713	36495.07
RM	-59.5	-16.25	40.0	20.0	-1190	-325	800	42.71713	36495.07
LR	-102.5	16.25	40.0	20.0	-2050	325	800	84.79552	143805.6
RR	-102.5	-16.25	40.0	20.0	-2050	-325	800	84.79552	143805.6
Ride Ht. Adjuster	59.5	16.25	40.0	10.0	595	162.5	400	79.08204	62539.69
RF	59.5	-16.25	40.0	10.0	595	-162.5	400	79.08204	62539.69
LM	-59.5	16.25	40.0	10.0	-595	162.5	400	42.71713	18247.53
RM	-59.5	-16.25	40.0	10.0	-595	-162.5	400	42.71713	18247.53
LR	-102.5	16.25	40.0	10.0	-1025	162.5	400	84.79552	71902.81
RR	-102.5	-16.25	40.0	10.0	-1025	-162.5	400	84.79552	71902.81
Rockers LM	-45.0	16.25	33.0	14.0	-630	227.5	462	26.92871	10152.18
RM	-45.0	-16.25	33.0	14.0	-630	-227.5	462	26.92871	10152.18
RR	-88.0	-16.25	33.0	14.0	-1232	-227.5	462	69.59657	67811.56
RR	-88.0	-16.25	33.0	14.0	-1232	-227.5	462	69.59657	67811.56
Steering								33.32115	0
Box	56.0	-6.0	18.0	26.0	1456	-156	468	75.23032	147149.6
Rockers/Links	50.7	-8.1	19.5	20.0	1014	-162	390	69.78649	97403.07
Shaft	23.1	-17.0	34.0	3.5	80.85	-59.5	119	42.19227	6230.658
Wheel	10.0	-17.0	38.8	3.3	33	-56.1	128.04	30.70976	3112.196
Chassis								33.32115	0
Frame	-16.0	0.0	30.0	600.0	-9600	0	18000	3.518977	7429.918
Bumper	77.8	0.0	26.2	50.0	3890	0	1310	96.4209	464849.5
Body								33.32115	0
Panels/Covers/Dash	0.0	0.0	30.0	100.0	0	0	3000	18.75921	35190.79
Seats	0.0	0.0	40.0	46.0	0	0	1840	22.34079	22959.11
Mounts	0.0	0.0	13.15	26.0	0	0	341.9	23.58587	14463.62
Rear Deck	-55.1	0.0	29.5	34.4	-1895.44	0	1014.8	36.53723	45922.95
Wheel Arches	59.5	22.0	30.0	11.0	654.5	242	330	78.1458	67174.42
RF	59.5	-22.0	30.0	11.0	654.5	-242	330	78.1458	67174.42
LM	-59.5	22.0	30.0	11.0	-654.5	242	330	40.95791	18453.05
RM	-59.5	-22.0	30.0	11.0	-654.5	-242	330	40.95791	18453.05
LR	-102.5	22.0	30.0	11.0	-1127.5	242	330	83.92305	77473.85
RR	-102.5	-22.0	30.0	11.0	-1127.5	-242	330	83.92305	77473.85
Skid Plate	0.0	0.0	12.0	120.0	0	0	1440	24.30931	70913.09
Windshield	26.2	0.0	52.9	33.0	864.6	0	1745.7	51.43952	87318.82
Electrical Harness	0.0	0.0	25.0	90.0	0	0	2250	18.79645	31797.58
Plumbing	0.0	0.0	25.0	20.0	0	0	500	18.79645	7066.128
Nuts & Bolts	0.0	0.0	25.0	50.0	0	0	1250	18.79645	17665.32
Fluids								33.32115	0
Fuel	-31.1	0.8	18.2	240.0	-7464	192	4368	15.6559	58825.71
Oil	11.5	0.8	15.6	20.0	230	16	312	32.42806	21031.58
Water	74.0	0.0	24.2	26.0	1924	0	629.2	92.67401	223300.3
		Weight Subtotal		5875.7				33.32115	6523782
Accessories								33.32115	0
Driver	0.0	17.0	30.5	255.0	0	4335	7777.5	18.82865	90402.11
Navigator	0.0	-17.0	30.5	255.0	0	-4335	7777.5	18.82865	90402.11
Passenger	-35.0	17.0	30.5	255.0	-8925	4335	7777.5	16.63754	70585.97
Passenger	-35.0	-17.0	30.5	255.0	-8925	-4335	7777.5	16.63754	70585.97
Payload	-81.0	0.0	40.0	725.0	-58725	0	29000	63.60241	2932819
50 cal. Gun	-81.0	0.0	70.0	378.0	-30618	0	26460	75.41138	2149639
		Total Weight		7998.7	-148857	2314.4	221082.8	**I pitch**	25232863
	X	Y	Z						
Center of Gravity	78.11	0.29	27.64					**Radius of Gyration**	
Weight Distribution on Front		34							

RST-V 6x6 Series Parallel Hybrid Weight Distribution											
Vehicle Dimensions											
Length	211.7	in.									
Width	65.0	in.									
Height	66.0	in.								pitch axis	
Wheelbase	119.0	in.								moment of inertia	
Rear Wheelbase	162.0	in.									
	FRONT	WIDE	HEIGHT								
	Xcg	Ycg	Zcg	Weight		W*X	W*Y	W*Z		Pitch rad	mom of ine
Powertrain											
Engine	46.8	0.0	24.5	551.0		25786.8	0	13499.5		64.8511	2317321
alternator	20.0	0.0	24.5	85.0		1700	0	2082.5		38.10585	123424.7
Front Motor and gb	65.9	0.0	23.0	350.0		23065	0	8050		84.00352	2469807
Middle Motor and GB	-50.5	0.0	23.0	196.0		-9898	0	4508		32.86103	211650
Rear Motor and GB	-93.5	0.0	23.0	196.0		-18326	0	4508		75.67128	1122324
Front inverter	-10.0	20.0	35.0	50.0		-500	1000	1750		10.82686	5861.049
middle inverter	-10.0	0.0	35.0	50.0		-500	0	1750		10.82686	5861.049
rear inverter	-10.0	0.0	35.0	50.0		-500	0	1750		10.82686	5861.049
alternator inverter	-10.0	-20.0	35.0	75.0		-750	-1500	2625		10.82686	8791.573
Fuel Cells	-31.1	0.0	18.2	45.0		-1399.5	0	819		16.18939	11794.34
pumps and lines	-22.0	-17.0	21.0	16.0		-352	-272	336		7.795985	972.4381
Exhaust/Muffler	-8.0	-7.5	17.6	36.0		-288	-270	633.6		14.17687	7235.41
Radiator	74.0	0.0	24.2	45.0		3330	0	1089		92.03895	381202.5
Fan	78.0	0.0	0.0	0.0		0	0	0		99.88399	0
Intercooler	0.0	0.0	0.0	0.0		0	0	0		32.99964	0
Battery pack	0.0	0.0	18.13	1260.0		0	0	22843.8		20.35085	521838.1
Drivetrain										32.99964	0
LF HALFSHAFT	59.5	16.25	16.0	12.0		714	195	192		78.34814	73661.17
RF HALFSHAFT	59.5	-16.25	16.0	12.0		714	-195	192		78.34814	73661.17
LM HALFSHAFT	-59.5	16.25	16.0	12.0		-714	195	192		43.13682	22329.42
RM HALFSHAFT	-59.5	-16.25	16.0	12.0		-714	-195	192		43.13682	22329.42
LR HALFSHAFT	-102.5	16.25	16.0	12.0		-1230	195	192		85.32925	87372.98
RR HALFSHAFT	-102.5	-16.25	16.0	12.0		-1230	-195	192		85.32925	87372.98
Shifter	4.0	-4.0	32.6	8.0		32	-32	260.8		22.51835	4056.609
Throttle	32.9	-17.0	30.8	2.0		65.8	-34	61.6		50.96916	5195.71
Brake	32.9	-17.0	30.8	6.0		197.4	-102	184.8		50.96916	15587.13
Hand brake	-8.0	2.0	32.6	2.5		-20	5	81.5		11.12281	309.2921
Suspension										32.99964	0
Tires/Wheels LF	59.5	26.0	15.15	72.0		4284	1872	1090.8		78.47931	443448.1
RF	59.5	-26.0	15.15	72.0		4284	-1872	1090.8		78.47931	443448.1
LM	-59.5	26.0	15.15	72.0		-4284	1872	1090.8		43.3746	135457.7
RM	-59.5	-26.0	15.15	72.0		-4284	-1872	1090.8		43.3746	135457.7
LR	-102.5	26.0	15.15	72.0		-7380	1872	1090.8		85.44971	525719
RR	-102.5	-26.0	15.15	72.0		-7380	-1872	1090.8		85.44971	525719
Upright LF	59.5	26.0	15.15	14.0		833	364	212.1		78.47931	86226.03
RF	59.5	-26.0	15.15	14.0		833	-364	212.1		78.47931	86226.03
LM	-59.5	26.0	15.15	14.0		-833	364	212.1		43.3746	26338.99
RM	-59.5	-26.0	15.15	14.0		-833	-364	212.1		43.3746	26338.99
LR	-102.5	26.0	15.15	14.0		-1435	364	212.1		85.44971	102223.1
RR	-102.5	-26.0	15.15	14.0		-1435	-364	212.1		85.44971	102223.1
Rotor	59.5	26.0	15.15	10.0		595	260	151.5		78.47931	61590.02
RF	59.5	-26.0	15.15	10.0		595	-260	151.5		78.47931	61590.02
LM	-59.5	26.0	15.15	10.0		-595	260	151.5		43.3746	18813.56
RM	-59.5	-26.0	15.15	10.0		-595	-260	151.5		43.3746	18813.56
LR	-102.5	26.0	15.15	10.0		-1025	260	151.5		85.44971	73016.52
RR	-102.5	-26.0	15.15	10.0		-1025	-260	151.5		85.44971	73016.52
Caliper	59.5	26.0	15.15	7.0		416.5	182	106.05		78.47931	43113.01
RF	59.5	-26.0	15.15	7.0		416.5	-182	106.05		78.47931	43113.01
LM	-59.5	26.0	15.15	7.0		-416.5	182	106.05		43.3746	13169.49
RM	-59.5	-26.0	15.15	7.0		-416.5	-182	106.05		43.3746	13169.49
LR	-102.5	26.0	15.15	7.0		-717.5	182	106.05		85.44971	51111.57
RR	-102.5	-26.0	15.15	7.0		-717.5	-182	106.05		85.44971	51111.57
Upper A-arm	59.5	16.25	21.2	13.0		773.5	211.25	275.6		77.74346	78572.59
RF	59.5	-16.25	21.2	13.0		773.5	-211.25	275.6		77.74346	78572.59
LM	-59.5	16.25	11.6	18.0		-1071	292.5	208.8		44.52966	35692.03
RM	-59.5	-16.25	11.6	18.0		-1071	-292.5	208.8		44.52966	35692.03
LR	-102.5	16.25	11.6	18.0		-1845	292.5	208.8		86.04177	133257.4
RR	-102.5	-16.25	11.6	18.0		-1845	-292.5	208.8		86.04177	133257.4
Lower A-arm	59.5	16.25	11.6	19.0		1130.5	308.75	220.4		79.12355	118950.2
RF	59.5	-16.25	11.6	19.0		1130.5	-308.75	220.4		79.12355	118950.2
LM	-59.5	16.25	11.6	18.0		-1071	292.5	208.8		44.52966	35692.03
RM	-59.5	-16.25	11.6	18.0		-1071	-292.5	208.8		44.52966	35692.03
LR	-102.5	16.25	11.6	18.0		-1845	292.5	208.8		86.04177	133257.4
RR	-102.5	-16.25	11.6	18.0		-1845	-292.5	208.8		86.04177	133257.4
Shocks	59.5	16.25	27.0	23.5		1398.25	381.875	634.5		77.47625	141060.4
RF	59.5	-16.25	27.0	23.5		1398.25	-381.875	634.5		77.47625	141060.4

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LM	-59.5	16.25	40.0	23.5	-1398.25	381.875	940	43.31695	44094.43
RM	-59.5	-16.25	40.0	23.5	-1398.25	-381.875	940	43.31695	44094.43
LR	-102.5	16.25	40.0	23.5	-2408.75	381.875	940	85.42046	171471.4
RR	-102.5	-16.25	40.0	23.5	-2408.75	-381.875	940	85.42046	171471.4
Springs	59.5	16.25	27.0	20.0	1190	325	540	77.47625	120051.4
RF	59.5	-16.25	27.0	20.0	1190	-325	540	77.47625	120051.4
LM	-59.5	16.25	40.0	20.0	-1190	325	800	43.31695	37527.17
RM	-59.5	-16.25	40.0	20.0	-1190	-325	800	43.31695	37527.17
LR	-102.5	16.25	40.0	20.0	-2050	325	800	85.42046	145933.1
RR	-102.5	-16.25	40.0	20.0	-2050	-325	800	85.42046	145933.1
Ride Ht. Adjuster	59.5	16.25	40.0	10.0	595	162.5	400	78.44746	61540.04
RF	59.5	-16.25	40.0	10.0	595	-162.5	400	78.44746	61540.04
LM	-59.5	16.25	40.0	10.0	-595	162.5	400	43.31695	18763.59
RM	-59.5	-16.25	40.0	10.0	-595	-162.5	400	43.31695	18763.59
LR	-102.5	16.25	40.0	10.0	-1025	162.5	400	85.42046	72966.55
RR	-102.5	-16.25	40.0	10.0	-1025	-162.5	400	85.42046	72966.55
Rockers LM	-45.0	16.25	33.0	14.0	-630	227.5	462	27.54618	10623.09
RM	-45.0	-16.25	33.0	14.0	-630	-227.5	462	27.54618	10623.09
RR	-88.0	-16.25	33.0	14.0	-1232	-227.5	462	70.22883	69049.24
RR	-88.0	-16.25	33.0	14.0	-1232	-227.5	462	70.22883	69049.24
Steering								32.99964	0
Box	56.0	-6.0	18.0	26.0	1456	-156	468	74.60339	144707.3
Rockers/Links	50.7	-8.1	19.5	20.0	1014	-162	390	69.15824	95657.24
Shaft	23.1	-17.0	34.0	3.5	80.85	-59.5	119	41.55737	6044.551
Wheel	10.0	-17.0	38.8	3.3	33	-56.1	128.04	30.10413	2990.654
Chassis								32.99964	0
Frame	-16.0	0.0	30.0	600.0	-9600	0	18000	3.049089	5578.168
Bumper	77.8	0.0	26.2	50.0	3890	0	1310	95.78467	458735.1
Body								32.99964	0
Panels/Covers/Dash	0.0	0.0	30.0	100.0	0	0	3000	18.12298	32844.26
Seats	0.0	0.0	40.0	46.0	0	0	1840	21.79292	21846.84
Mounts	0.0	0.0	13.15	26.0	0	0	341.9	23.10912	13884.82
Rear Deck	-55.1	0.0	29.5	34.4	-1895.44	0	1014.8	37.1715	47531.18
Wheel Arches	59.5	22.0	30.0	11.0	654.5	242	330	77.50816	66082.67
RF	59.5	-22.0	30.0	11.0	654.5	-242	330	77.50816	66082.67
LM	-59.5	22.0	30.0	11.0	-654.5	242	330	41.5917	19028.57
RM	-59.5	-22.0	30.0	11.0	-654.5	-242	330	41.5917	19028.57
LR	-102.5	22.0	30.0	11.0	-1127.5	242	330	84.55865	78651.82
RR	-102.5	-22.0	30.0	11.0	-1127.5	-242	330	84.55865	78651.82
Skid Plate	0.0	0.0	12.0	120.0	0	0	1440	23.84875	68251.52
Windshield	26.2	0.0	52.9	33.0	864.6	0	1745.7	50.868	85389.25
Electrical Harness	0.0	0.0	25.0	90.0	0	0	2250	18.17136	29717.83
Plumbing	0.0	0.0	25.0	20.0	0	0	500	18.17136	6603.963
Nuts & Bolts	0.0	0.0	25.0	50.0	0	0	1250	18.17136	16509.91
Fluids								32.99964	0
Fuel	-31.1	0.8	18.2	240.0	-7464	192	4368	16.18939	62903.14
Oil	11.5	0.8	15.6	20.0	230	16	312	31.85113	20289.89
Water	74.0	0.0	24.2	26.0	1924	0	629.2	92.03895	220250.4
		Weight Subtotal		5872.7				32.99964	6395230
Accessories								32.99964	0
Driver	0.0	17.0	30.5	255.0	0	4335	7777.5	18.19387	84409.34
Navigator	0.0	-17.0	30.5	255.0	0	-4335	7777.5	18.19387	84409.34
Passenger	-35.0	17.0	30.5	255.0	-8925	4335	7777.5	17.25937	75960.92
Passenger	-35.0	-17.0	30.5	255.0	-8925	-4335	7777.5	17.25937	75960.92
Payload	-81.0	0.0	40.0	730.0	-59130	0	29200	64.22038	3010707
50 cal. Gun	-81.0	0.0	70.0	378.0	-30618	0	26460	75.91919	2178687
		Total Weight		8000.7	-143799	-1885.6	221423.8	**I pitch**	27175906
	X	**Y**	**Z**						
Center of Gravity	77.47	-0.24	27.68					**Radius of Gyration**	
Weight Distribution on Front		35							

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RST-V 6x6 Series Hybrid Weight Distribution											
Vehicle Dimensions											
Length	211.7	in.									
Width	65.0	in.									
Height	66.0	in.								pitch axis	
Wheelbase	119.0	in.								moment of inertia	
Rear Wheelbase	162.0	in.									
	FRONT	WIDE	HEIGHT								
	Xcg	Ycg	Zcg	Weight		W*X	W*Y	W*Z		Pitch rad	mom of ine
Powertrain											
Engine	46.8	0.0	24.5	551.0		25786.8	0	13499.5		67.66878	2523064
alternator	20.0	0.0	24.5	85.0		1700	0	2082.5		40.92808	142384.1
Front Motor and gb	65.9	0.0	23.0	196.0		12916.4	0	4508		86.82229	1477470
Middle Motor and GB	-50.5	0.0	23.0	196.0		-9898	0	4508		30.13905	178039
Rear Motor and GB	-93.5	0.0	23.0	196.0		-18326	0	4508		72.89327	1041432
Front inverter	-10.0	20.0	35.0	50.0		-500	1000	1750		12.85285	8259.789
middle inverter	-10.0	0.0	35.0	50.0		-500	0	1750		12.85285	8259.789
rear inverter	-10.0	0.0	35.0	50.0		-500	0	1750		12.85285	8259.789
alternator inverter	-10.0	-20.0	35.0	75.0		-750	-1500	2625		12.85285	12389.68
Fuel Cells	-31.1	0.0	18.2	45.0		-1399.5	0	819		14.23179	9114.472
pumps and lines	-22.0	-17.0	21.0	16.0		-352	-272	336		7.104117	807.4956
Exhaust/Muffler	-8.0	-7.5	17.6	36.0		-288	-270	633.6		16.4745	9770.728
Radiator	74.0	0.0	24.2	45.0		3330	0	1089		94.85438	404880.9
Fan	78.0	0.0	0.0	0.0		0	0	0		102.6696	0
Intercooler	0.0	0.0	0.0	0.0		0	0	0		34.86605	0
Battery pack	0.0	0.0	18.13	1260.0		0	0	22843.8		23.00262	666691.9
Drivetrain										34.86605	0
LF HALFSHAFT	59.5	16.25	16.0	12.0		714	195	192		81.16997	79062.77
RF HALFSHAFT	59.5	-16.25	16.0	12.0		714	-195	192		81.16997	79062.77
LM HALFSHAFT	-59.5	16.25	16.0	12.0		-714	195	192		40.53799	19719.95
RM HALFSHAFT	-59.5	-16.25	16.0	12.0		-714	-195	192		40.53799	19719.95
LR HALFSHAFT	-102.5	16.25	16.0	12.0		-1230	195	192		82.59779	81868.74
RR HALFSHAFT	-102.5	-16.25	16.0	12.0		-1230	-195	192		82.59779	81868.74
Shifter	4.0	-4.0	32.6	8.0		32	-32	260.8		25.20198	5081.119
Throttle	32.9	-17.0	30.8	2.0		65.8	-34	61.6		53.75137	5778.419
Brake	32.9	-17.0	30.8	6.0		197.4	-102	184.8		53.75137	17335.26
Hand brake	-8.0	2.0	32.6	2.5		-20	5	81.5		13.58163	461.1518
Suspension										34.86605	0
Tires/Wheels LF	59.5	26.0	15.15	72.0		4284	1872	1090.8		81.29996	475897.2
RF	59.5	-26.0	15.15	72.0		4284	-1872	1090.8		81.29996	475897.2
LM	-59.5	26.0	15.15	72.0		-4284	1872	1090.8		40.79765	119840.3
RM	-59.5	-26.0	15.15	72.0		-4284	-1872	1090.8		40.79765	119840.3
LR	-102.5	26.0	15.15	72.0		-7380	1872	1090.8		82.72554	492733.1
RR	-102.5	-26.0	15.15	72.0		-7380	-1872	1090.8		82.72554	492733.1
Upright LF	59.5	26.0	15.15	14.0		833	364	212.1		81.29996	92535.57
RF	59.5	-26.0	15.15	14.0		833	-364	212.1		81.29996	92535.57
LM	-59.5	26.0	15.15	14.0		-833	364	212.1		40.79765	23302.28
RM	-59.5	-26.0	15.15	14.0		-833	-364	212.1		40.79765	23302.28
LR	-102.5	26.0	15.15	14.0		-1435	364	212.1		82.72554	95809.21
RR	-102.5	-26.0	15.15	14.0		-1435	-364	212.1		82.72554	95809.21
Rotor	59.5	26.0	15.15	10.0		595	260	151.5		81.29996	66096.83
RF	59.5	-26.0	15.15	10.0		595	-260	151.5		81.29996	66096.83
LM	-59.5	26.0	15.15	10.0		-595	260	151.5		40.79765	16644.49
RM	-59.5	-26.0	15.15	10.0		-595	-260	151.5		40.79765	16644.49
LR	-102.5	26.0	15.15	10.0		-1025	260	151.5		82.72554	68435.15
RR	-102.5	-26.0	15.15	10.0		-1025	-260	151.5		82.72554	68435.15
Caliper	59.5	26.0	15.15	7.0		416.5	182	106.05		81.29996	46267.78
RF	59.5	-26.0	15.15	7.0		416.5	-182	106.05		81.29996	46267.78
LM	-59.5	26.0	15.15	7.0		-416.5	182	106.05		40.79765	11651.14
RM	-59.5	-26.0	15.15	7.0		-416.5	-182	106.05		40.79765	11651.14
LR	-102.5	26.0	15.15	7.0		-717.5	182	106.05		82.72554	47904.6
RR	-102.5	-26.0	15.15	7.0		-717.5	-182	106.05		82.72554	47904.6
Upper A-arm	59.5	16.25	21.2	13.0		773.5	211.25	275.6		80.56564	84380.68
RF	59.5	-16.25	21.2	13.0		773.5	-211.25	275.6		80.56564	84380.68
LM	-59.5	16.25	11.6	18.0		-1071	292.5	208.8		42.05085	31828.93
RM	-59.5	-16.25	11.6	18.0		-1071	-292.5	208.8		42.05085	31828.93
LR	-102.5	16.25	11.6	18.0		-1845	292.5	208.8		83.35071	125052.1
RR	-102.5	-16.25	11.6	18.0		-1845	-292.5	208.8		83.35071	125052.1
Lower A-arm	59.5	16.25	11.6	19.0		1130.5	308.75	220.4		81.936	127556.7
RF	59.5	-16.25	11.6	19.0		1130.5	-308.75	220.4		81.936	127556.7
LM	-59.5	16.25	11.6	18.0		-1071	292.5	208.8		42.05085	31828.93
RM	-59.5	-16.25	11.6	18.0		-1071	-292.5	208.8		42.05085	31828.93
LR	-102.5	16.25	11.6	18.0		-1845	292.5	208.8		83.35071	125052.1
RR	-102.5	-16.25	11.6	18.0		-1845	-292.5	208.8		83.35071	125052.1
Shocks	59.5	16.25	27.0	23.5		1398.25	381.875	634.5		80.2845	151471.6
RF	59.5	-16.25	27.0	23.5		1398.25	-381.875	634.5		80.2845	151471.6

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LM	-59.5	16.25	40.0	23.5		-1398.25	381.875	940		40.53901	38620.17
RM	-59.5	-16.25	40.0	23.5		-1398.25	-381.875	940		40.53901	38620.17
LR	-102.5	16.25	40.0	23.5		-2408.75	381.875	940		82.59829	160328.2
RR	-102.5	-16.25	40.0	23.5		-2408.75	-381.875	940		82.59829	160328.2
Springs	59.5	16.25	27.0	20.0		1190	325	540		80.2845	128912
RF	59.5	-16.25	27.0	20.0		1190	-325	540		80.2845	128912
LM	-59.5	16.25	40.0	20.0		-1190	325	800		40.53901	32868.23
RM	-59.5	-16.25	40.0	20.0		-1190	-325	800		40.53901	32868.23
LR	-102.5	16.25	40.0	20.0		-2050	325	800		82.59829	136449.6
RR	-102.5	-16.25	40.0	20.0		-2050	-325	800		82.59829	136449.6
Ride Ht. Adjuster	59.5	16.25	40.0	10.0		595	162.5	400		81.17048	65886.46
RF	59.5	-16.25	40.0	10.0		595	-162.5	400		81.17048	65886.46
LM	-59.5	16.25	40.0	10.0		-595	162.5	400		40.53901	16434.12
RM	-59.5	-16.25	40.0	10.0		-595	-162.5	400		40.53901	16434.12
LR	-102.5	16.25	40.0	10.0		-1025	162.5	400		82.59829	68224.78
RR	-102.5	-16.25	40.0	10.0		-1025	-162.5	400		82.59829	68224.78
Rockers LM	-45.0	16.25	33.0	14.0		-630	227.5	462		24.73273	8563.913
RM	-45.0	-16.25	33.0	14.0		-630	-227.5	462		24.73273	8563.913
RR	-88.0	-16.25	33.0	14.0		-1232	-227.5	462		67.40753	63612.84
RR	-88.0	-16.25	33.0	14.0		-1232	-227.5	462		67.40753	63612.84
Steering										34.86605	0
Box	56.0	-6.0	18.0	26.0		1456	-156	468		77.42656	155866.7
Rockers/Links	50.7	-8.1	19.5	20.0		1014	-162	390		71.98172	103627.4
Shaft	23.1	-17.0	34.0	3.5		80.85	-59.5	119		44.28686	6864.64
Wheel	10.0	-17.0	38.8	3.3		33	-56.1	128.04		32.61872	3511.137
Chassis										34.86605	0
Frame	-16.0	0.0	30.0	600.0		-9600	0	18000		5.180638	16103.41
Bumper	77.8	0.0	26.2	50.0		3890	0	1310		98.5947	486045.7
Body										34.86605	0
Panels/Covers/Dash	0.0	0.0	30.0	100.0		0	0	3000		20.87449	43574.45
Seats	0.0	0.0	40.0	46.0		0	0	1840		23.99539	26485.83
Mounts	0.0	0.0	13.15	26.0		0	0	341.9		25.53838	16957.44
Rear Deck	-55.1	0.0	29.5	34.4		-1895.44	0	1014.8		34.35454	40600.06
Wheel Arches	59.5	22.0	30.0	11.0		654.5	242	330		80.30325	70934.73
RF	59.5	-22.0	30.0	11.0		654.5	-242	330		80.30325	70934.73
LM	-59.5	22.0	30.0	11.0		-654.5	242	330		38.77341	16537.15
RM	-59.5	-22.0	30.0	11.0		-654.5	-242	330		38.77341	16537.15
LR	-102.5	22.0	30.0	11.0		-1127.5	242	330		81.74621	73506.88
RR	-102.5	-22.0	30.0	11.0		-1127.5	-242	330		81.74621	73506.88
Skid Plate	0.0	0.0	12.0	120.0		0	0	1440		26.2237	82521.91
Windshield	26.2	0.0	52.9	33.0		864.6	0	1745.7		53.17007	93292.85
Electrical Harness	0.0	0.0	25.0	90.0		0	0	2250		20.99351	39665.46
Plumbing	0.0	0.0	25.0	20.0		0	0	500		20.99351	8814.547
Nuts & Bolts	0.0	0.0	25.0	50.0		0	0	1250		20.99351	22036.37
Fluids										34.86605	0
Fuel	-31.1	0.8	18.2	240.0		-7464	192	4368		14.23179	48610.52
Oil	11.5	0.8	15.6	20.0		230	16	312		34.57753	23912.12
Water	74.0	0.0	24.2	26.0		1924	0	629.2		94.85438	233931.2
		Weight Subtotal		5718.7						34.86605	6951888
Accessories										34.86605	0
Driver	0.0	17.0	30.5	255.0		0	4335	7777.5		20.92836	111689
Navigator	0.0	-17.0	30.5	255.0		0	-4335	7777.5		20.92836	111689
Passenger	-35.0	17.0	30.5	255.0		-8925	4335	7777.5		14.44006	53171.43
Passenger	-35.0	-17.0	30.5	255.0		-8925	-4335	7777.5		14.44006	53171.43
Payload	-81.0	0.0	40.0	881.0		-71361	0	35240		61.40598	3321982
50 cal. Gun	-81.0	0.0	70.0	378.0		-30618	0	26460		73.42205	2037722
		Total Weight		7997.7		-166179	-1885.6	223921.8		I pitch	27204852
	X	Y	Z								
Center of Gravity	80.28	-0.24	28.0							Radius of Gyration	
Weight Distribution on Front		33									

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Appendix E Ackerman Steering Analysis

ACKERMAN STEERING ANGLES

CASE 1: 4 WHEELED VEHICLE

a	b	c1	c2
1	-84.265	-54575	-86975

R	L	t	δ_o	δ_i
240	120	55	30.00	38.14
240	130	55	32.80	[illegible]
240	140	55	35.69	[illegible]
240	150	55	38.68	[illegible]
240	160	55	[illegible]	[illegible]
300	120	55	23.58	28.62
300	130	55	25.68	31.12
300	140	55	27.82	33.65
300	150	55	30.00	36.22
300	160	55	32.23	38.83

R	L1	L2	x	t	Ro1	δ_o	δ_i	δ_3	δ_4
240	125.50	130.00	149.57	55	195.25	31.53	40.00	1.26	1.72
240	125.50	140.00	149.57	55	195.25	31.53	40.00	4.05	5.54
240	125.50	150.00	149.57	55	195.25	31.53	40.00	6.83	9.30
240	125.50	160.00	149.57	55	195.25	31.53	40.00	9.57	12.99

CASE 2: 6 WHEELED VEHICLE WITH STANDARD ACKERMAN

R	L1	L2	t	δ_o	δ_i
240	80	122	55	24.89	31.83
240	90	132	55	27.55	35.13
240	100	142	55	30.28	38.47
240	110	152	55	33.08	41.88
240	120	162	55	35.98	[illegible]
300	80	122	55	19.67	23.94
300	90	132	55	21.72	26.39
300	100	142	55	23.79	28.86
300	110	152	55	25.89	31.37
300	120	162	55	28.03	33.90

R	L1+L2	Y	t	Ro1	δ_o	δ_i
240	251.01	125.50	55	195.25	31.53	40.00

CASE 3: 6 WHEELED VEHICLE WITH REAR AXLE FIXED, FRONT TWO STEERING

R	L1	L2	t	δ_1	δ_2	δ_3	δ_4
240	80	122	55	30.55	38.81	11.49	15.48
240	90	132	55	33.37	42.23	11.83	16.11
240	100	142	55	36.28	45.72	12.25	16.87
240	110	152	55	39.30	49.30	12.74	17.81
240	120	162	55	42.45	53.00	13.34	18.99
300	80	122	55	24.00	29.11	8.71	10.85
300	90	132	55	26.10	31.62	8.86	11.06
300	100	142	55	28.25	34.16	9.03	11.35
300	110	152	55	30.44	36.74	9.22	11.65
300	120	162	55	32.68	39.36	9.44	12.01

R	L2	x1	x	t	R2	δ_1	δ_2	δ_3	δ_4
240	125.50	42	149.57	55	195.25	31.53	40.00	11.60	15.69
240	125.50	42	149.57	55	195.25	31.53	40.00	11.60	15.69
240	125.50	42	149.57	55	195.25	31.53	40.00	11.60	15.69
240	125.50	42	149.57	55	195.25	31.53	40.00	11.60	15.69

CASE 4: 6 WHEELED VEHICLE WITH CENTER AXLE FIXED

R	L1	L2	t	δ_1	δ_2	δ_3	δ_4
240	80	122	55	19.47	25.04	10.52	13.78
240	90	132	55	22.02	28.25	10.69	14.08
240	100	142	55	24.62	31.50	10.90	14.43
240	110	152	55	27.28	34.79	11.14	14.86
240	120	162	55	30.00	38.14	11.42	15.36
300	80	122	55	15.47	18.86	8.26	10.17
300	90	132	55	17.46	21.27	8.35	10.30
300	100	142	55	19.47	23.70	8.45	10.44
300	110	152	55	21.51	26.14	8.56	10.61
300	120	162	55	23.58	28.62	8.68	10.81

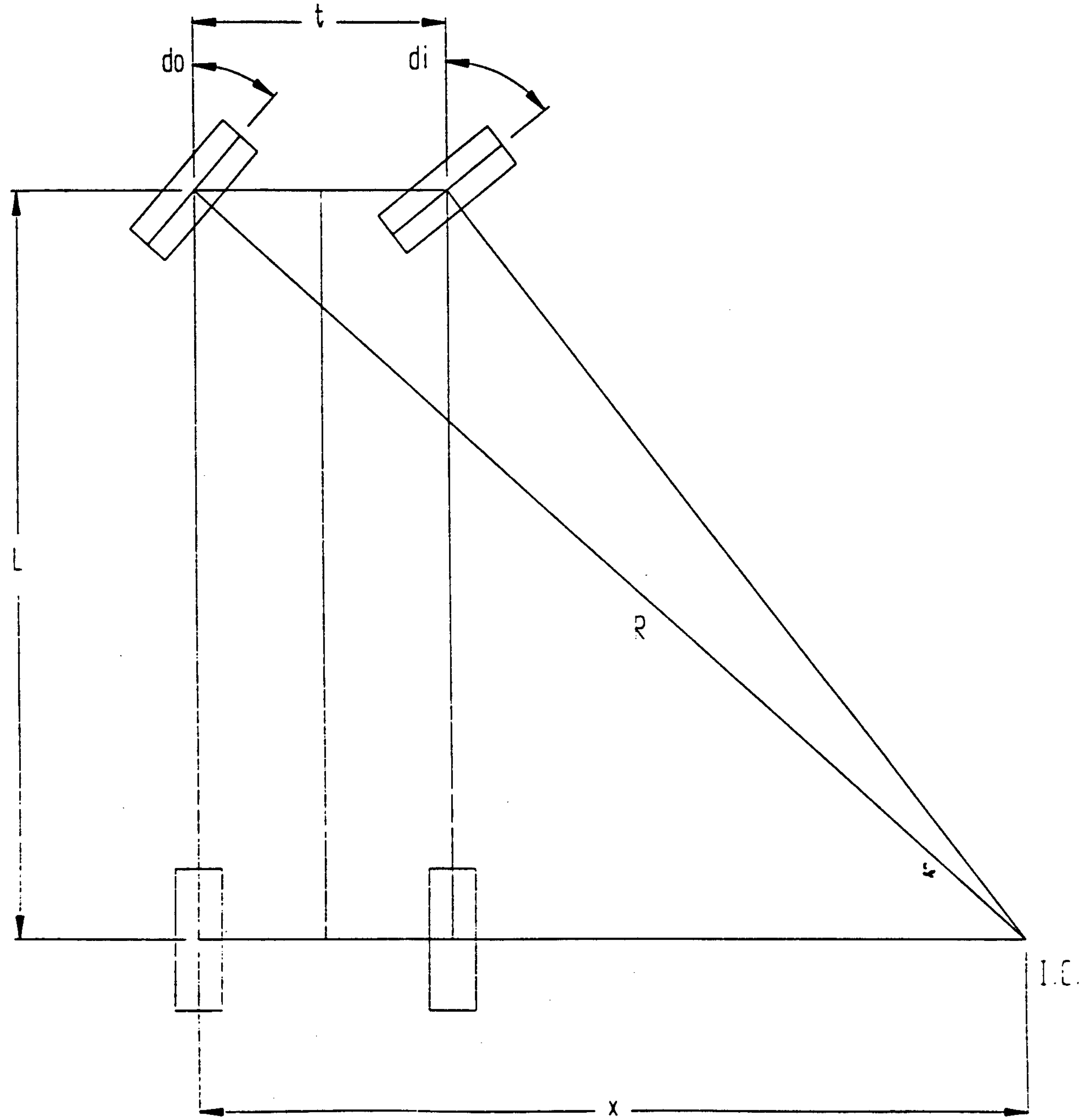
	A	B	C	D	E	F
1	ACKERMAN					
2						
3	CASE 1					
4						
5	R	L	t	δ_o	δ_i	
6	240	120	55	=ASIN(B6/A6)*180/PI()	=(ATAN(B6/(SQRT((A6^2)-(B6^2))-C6)))*180/PI()	
7	240	130	55	=ASIN(B7/A7)*180/PI()	=(ATAN(B7/(SQRT((A7^2)-(B7^2))-C7)))*180/PI()	
8	240	140	55	=ASIN(B8/A8)*180/PI()	[illegible]	
9	240	150	55	=ASIN(B9/A9)*180/PI()	=(ATAN(B9/(SQRT((A9^2)-(B9^2))-C9)))*180/PI()	
10	240	160	55	[illegible]	=(ATAN(B10/(SQRT((A10^2)-(B10^2))-C10)))*180/PI()	
11						
12	300	120	55	=ASIN(B12/A12)*180/PI()	=(ATAN(B12/(SQRT((A12^2)-(B12^2))-C12)))*180/PI()	
13	300	130	55	=ASIN(B13/A13)*180/PI()	=(ATAN(B13/(SQRT((A13^2)-(B13^2))-C13)))*180/PI()	
14	300	140	55	=ASIN(B14/A14)*180/PI()	=(ATAN(B14/(SQRT((A14^2)-(B14^2))-C14)))*180/PI()	
15	300	150	55	=ASIN(B15/A15)*180/PI()	=(ATAN(B15/(SQRT((A15^2)-(B15^2))-C15)))*180/PI()	
16	300	160	55	=ASIN(B16/A16)*180/PI()	=(ATAN(B16/(SQRT((A16^2)-(B16^2))-C16)))*180/PI()	
17						
18	CASE 2					
19						
20	R	L1	L2	t	δ_o	δ_i
21	240	120	162	55	=ASIN(((C21+B21)/2)/A21)*180/PI()	[illegible]
22	240	130	172	55	=ASIN(((C22+B22)/2)/A22)*180/PI()	=ATAN(((B22+C22)/2)/(SQRT((A22^2)-((B22+C22)/2)^2)-D22))*180/PI()
23	240	140	182	55	=ASIN(((C23+B23)/2)/A23)*180/PI()	=ATAN(((B23+C23)/2)/(SQRT((A23^2)-((B23+C23)/2)^2)-D23))*180/PI()
24	240	150	192	55	=ASIN(((C24+B24)/2)/A24)*180/PI()	=ATAN(((B24+C24)/2)/(SQRT((A24^2)-((B24+C24)/2)^2)-D24))*180/PI()
25	240	160	202	55	=ASIN(((C25+B25)/2)/A25)*180/PI()	=ATAN(((B25+C25)/2)/(SQRT((A25^2)-((B25+C25)/2)^2)-D25))*180/PI()
26						
27	300	120	162	55	=ASIN(((C27+B27)/2)/A27)*180/PI()	=ATAN(((B27+C27)/2)/(SQRT((A27^2)-((B27+C27)/2)^2)-D27))*180/PI()
28	300	130	172	55	=ASIN(((C28+B28)/2)/A28)*180/PI()	=ATAN(((B28+C28)/2)/(SQRT((A28^2)-((B28+C28)/2)^2)-D28))*180/PI()
29	300	140	182	55	=ASIN(((C29+B29)/2)/A29)*180/PI()	=ATAN(((B29+C29)/2)/(SQRT((A29^2)-((B29+C29)/2)^2)-D29))*180/PI()
30	300	150	192	55	=ASIN(((C30+B30)/2)/A30)*180/PI()	[illegible]
31	300	160	202	55	=ASIN(((C31+B31)/2)/A31)*180/PI()	[illegible]
32						
33	CASE 3					
34						
35	R	L1	L2	t	δ_1	δ_2
36	240	120	162	55	[illegible]	[illegible]
37	240	130	172	55	=ASIN(C37/A37)*180/PI()	=ATAN(C37/(SQRT((A37^2)-(C37^2))-D37))*180/PI()
38	240	140	182	55	=ASIN(C38/A38)*180/PI()	=ATAN(C38/(SQRT((A38^2)-(C38^2))-D38))*180/PI()
39	240	150	192	55	=ASIN(C39/A39)*180/PI()	=ATAN(C39/(SQRT((A39^2)-(C39^2))-D39))*180/PI()
40	240	160	202	55	=ASIN(C40/A40)*180/PI()	=ATAN(C40/(SQRT((A40^2)-(C40^2))-D40))*180/PI()
41						
42	300	120	162	55	=ASIN(C42/A42)*180/PI()	=ATAN(C42/(SQRT((A42^2)-(C42^2))-D42))*180/PI()
43	300	130	172	55	=ASIN(C43/A43)*180/PI()	=ATAN(C43/(SQRT((A43^2)-(C43^2))-D43))*180/PI()
44	300	140	182	55	=ASIN(C44/A44)*180/PI()	=ATAN(C44/(SQRT((A44^2)-(C44^2))-D44))*180/PI()
45	300	150	192	55	=ASIN(C45/A45)*180/PI()	=ATAN(C45/(SQRT((A45^2)-(C45^2))-D45))*180/PI()
46	300	160	202	55	=ASIN(C46/A46)*180/PI()	=ATAN(C46/(SQRT((A46^2)-(C46^2))-D46))*180/PI()
47						
48	CASE 4					
49						
50	R	L1	L2	t	δ_1	δ_2
51	240	120	162	55	=ASIN(B51/A51)*180/PI()	=ATAN((B51/((SQRT((A51^2)-(B51^2))-D51))))*180/PI()
52	240	130	172	55	=ASIN(B52/A52)*180/PI()	[illegible]
53	240	140	182	55	=ASIN(B53/A53)*180/PI()	[illegible]
54	240	150	192	55	=ASIN(B54/A54)*180/PI()	[illegible]
55	240	160	202	55	=ASIN(B55/A55)*180/PI()	[illegible]
56						
57	300	120	162	55	=ASIN(B57/A57)*180/PI()	=ATAN((B57/((SQRT((A57^2)-(B57^2))-D57))))*180/PI()
58	300	130	172	55	=ASIN(B58/A58)*180/PI()	=ATAN((B58/((SQRT((A58^2)-(B58^2))-D58))))*180/PI()
59	300	140	182	55	=ASIN(B59/A59)*180/PI()	=ATAN((B59/((SQRT((A59^2)-(B59^2))-D59))))*180/PI()
60	300	150	192	55	=ASIN(B60/A60)*180/PI()	=ATAN((B60/((SQRT((A60^2)-(B60^2))-D60))))*180/PI()
61	300	160	202	55	=ASIN(B61/A61)*180/PI()	=ATAN((B61/((SQRT((A61^2)-(B61^2))-D61))))*180/PI()

	G	H	I	J	K
1					
2	a	b	c1	c2	
3	1	=2*C8*COS(0.77778*PI())	=-(A8^2)+(C8^2)	=-(A12^2)+(C12^2)	
4					
5	R	L1	L2	x	t
6					
7	240	=L7*SIN(O7*PI()/180)	=B7	=H7/TAN(O7*PI()/180)	55
8	240	=L8*SIN(O8*PI()/180)	=B8	=H8/TAN(O8*PI()/180)	55
9	240	=L9*SIN(O9*PI()/180)	=B9	=H9/TAN(O9*PI()/180)	55
10	240	=L10*SIN(O10*PI()/180)	=B10	=H10/TAN(O10*PI()/180)	55
11					
12					
13					
14					
15					
16					
17					
18					
19					
20		R	L1+L2	Y	t
21		240	=2*L21*SIN(140*PI()/180)	=I21/2	55
22		240	=2*L22*SIN(140*PI()/180)	=I22/2	55
23		240	=2*L23*SIN(140*PI()/180)	=I23/2	55
24		240	=2*L24*SIN(140*PI()/180)	=I24/2	55
25		240	=2*L25*SIN(140*PI()/180)	=I25/2	55
26					
27					
28					
29					
30		300	=2*L30*SIN(140*PI()/180)	=I30/2	55
31		300	=2*L31*SIN(140*PI()/180)	=I31/2	55
32					
33					
34					
35	δ3	δ4		R	L2
36	=ATAN((C36-B36)/(SQRT((A36^2)-(C36^2))))*180/PI()	=ATAN((C36-B36)/(SQRT((A36^2)-(C36^2))-D36))*180/PI()		240	=O36*SIN(Q36*PI()/180)
37	=ATAN((C37-B37)/(SQRT((A37^2)-(C37^2))))*180/PI()	=ATAN((C37-B37)/(SQRT((A37^2)-(C37^2))-D37))*180/PI()		240	=O37*SIN(Q37*PI()/180)
38	=ATAN((C38-B38)/(SQRT((A38^2)-(C38^2))))*180/PI()	=ATAN((C38-B38)/(SQRT((A38^2)-(C38^2))-D38))*180/PI()		240	=O38*SIN(Q38*PI()/180)
39	=ATAN((C39-B39)/(SQRT((A39^2)-(C39^2))))*180/PI()	=ATAN((C39-B39)/(SQRT((A39^2)-(C39^2))-D39))*180/PI()		240	=O39*SIN(Q39*PI()/180)
40	=ATAN((C40-B40)/(SQRT((A40^2)-(C40^2))))*180/PI()	=ATAN((C40-B40)/(SQRT((A40^2)-(C40^2))-D40))*180/PI()		240	=O40*SIN(Q40*PI()/180)
41					
42	=ATAN((C42-B42)/(SQRT((A42^2)-(C42^2))))*180/PI()	=ATAN((C42-B42)/(SQRT((A42^2)-(C42^2))-D42))*180/PI()			
43	=ATAN((C43-B43)/(SQRT((A43^2)-(C43^2))))*180/PI()	=ATAN((C43-B43)/(SQRT((A43^2)-(C43^2))-D43))*180/PI()		300	=O43*SIN(Q43*PI()/180)
44	=ATAN((C44-B44)/(SQRT((A44^2)-(C44^2))))*180/PI()	=ATAN((C44-B44)/(SQRT((A44^2)-(C44^2))-D44))*180/PI()		300	=O44*SIN(Q44*PI()/180)
45	=ATAN((C45-B45)/(SQRT((A45^2)-(C45^2))))*180/PI()	=ATAN((C45-B45)/(SQRT((A45^2)-(C45^2))-D45))*180/PI()		300	=O45*SIN(Q45*PI()/180)
46	=ATAN((C46-B46)/(SQRT((A46^2)-(C46^2))))*180/PI()	=ATAN((C46-B46)/(SQRT((A46^2)-(C46^2))-D46))*180/PI()		300	=O46*SIN(Q46*PI()/180)
47					
48					
49					
50	δ3	δ4		R	L1
51	=ATAN((C51-B51)/((SQRT((A51^2)-(B51^2)))))*180/PI()	=ATAN((C51-B51)/((SQRT((A51^2)-(B51^2))-D51)))*180/PI()			
52	=ATAN((C52-B52)/((SQRT((A52^2)-(B52^2)))))*180/PI()	=ATAN((C52-B52)/((SQRT((A52^2)-(B52^2))-D52)))*180/PI()		240	=O52*SIN(40*PI()/180)
53	=ATAN((C53-B53)/((SQRT((A53^2)-(B53^2)))))*180/PI()	=ATAN((C53-B53)/((SQRT((A53^2)-(B53^2))-D53)))*180/PI()		240	=O53*SIN(40*PI()/180)
54	=ATAN((C54-B54)/((SQRT((A54^2)-(B54^2)))))*180/PI()	=ATAN((C54-B54)/((SQRT((A54^2)-(B54^2))-D54)))*180/PI()		240	=O54*SIN(40*PI()/180)
55	=ATAN((C55-B55)/((SQRT((A55^2)-(B55^2)))))*180/PI()	=ATAN((C55-B55)/((SQRT((A55^2)-(B55^2))-D55)))*180/PI()		240	=O55*SIN(40*PI()/180)
56					
57	=ATAN((C57-B57)/((SQRT((A57^2)-(B57^2)))))*180/PI()	=ATAN((C57-B57)/((SQRT((A57^2)-(B57^2))-D57)))*180/PI()			
58	=ATAN((C58-B58)/((SQRT((A58^2)-(B58^2)))))*180/PI()	=ATAN((C58-B58)/((SQRT((A58^2)-(B58^2))-D58)))*180/PI()			
59	=ATAN((C59-B59)/((SQRT((A59^2)-(B59^2)))))*180/PI()	=ATAN((C59-B59)/((SQRT((A59^2)-(B59^2))-D59)))*180/PI()			
60	=ATAN((C60-B60)/((SQRT((A60^2)-(B60^2)))))*180/PI()	=ATAN((C60-B60)/((SQRT((A60^2)-(B60^2))-D60)))*180/PI()			
61	=ATAN((C61-B61)/((SQRT((A61^2)-(B61^2)))))*180/PI()	=ATAN((C61-B61)/((SQRT((A61^2)-(B61^2))-D61)))*180/PI()			

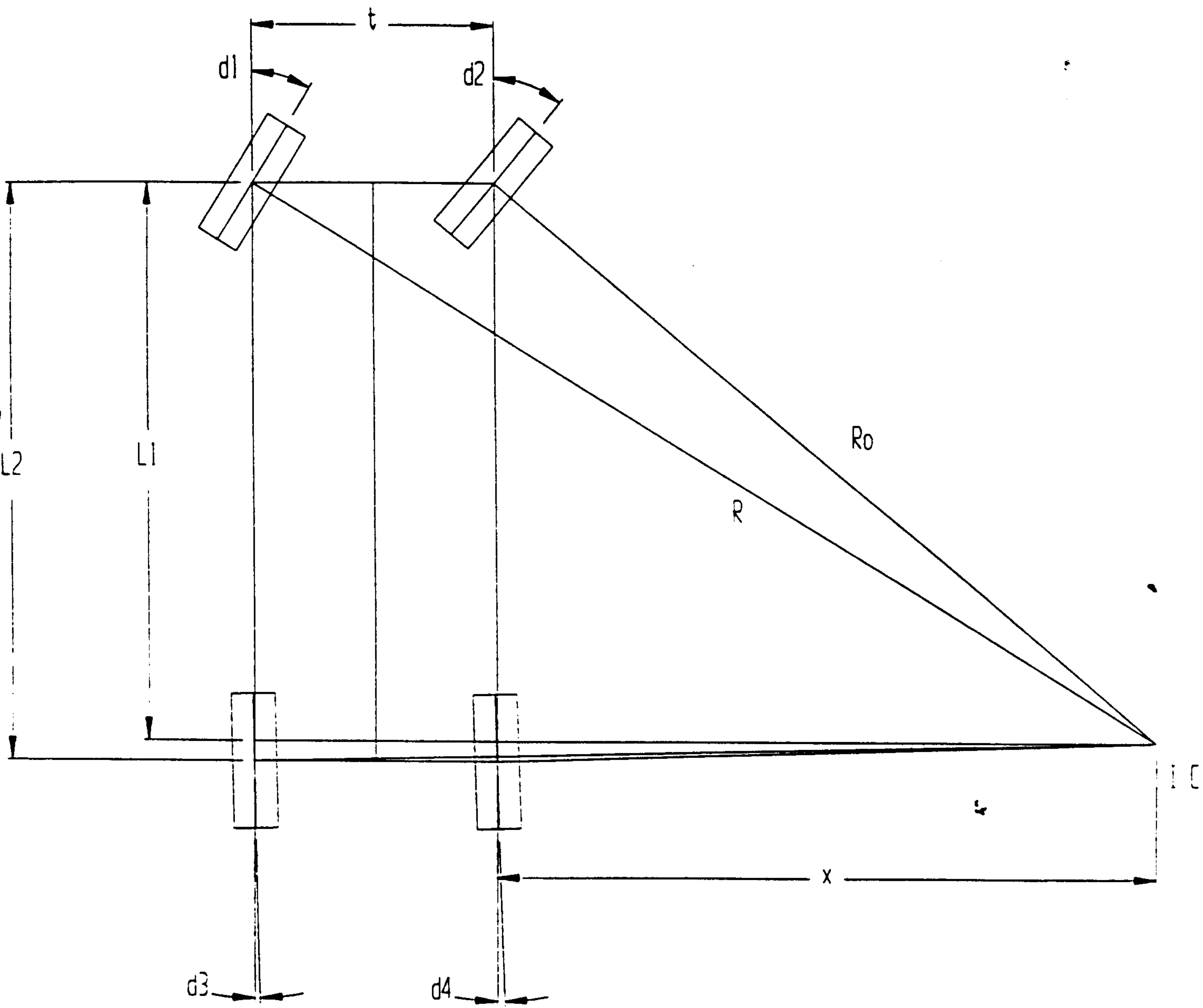
	L	M	N	O
1				
2				
3				
4				
5	Re1	Re2	δ_e	δi
6				
7	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)	=(H3-SQRT((H3^2)-4*G3*I3))/(2*G3)	=ASIN((L7*SIN(0.77778*PI()))/G7)*180/PI()	40
8	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)	=(H3-SQRT((H3^2)-4*G3*I3))/(2*G3)	=ASIN((L8*SIN(0.77778*PI()))/G8)*180/PI()	40
9	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)	=(H3-SQRT((H3^2)-4*G3*I3))/(2*G3)	=ASIN((L9*SIN(0.77778*PI()))/G9)*180/PI()	40
10	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)	=(H3-SQRT((H3^2)-4*G3*I3))/(2*G3)	=ASIN((L10*SIN(0.77778*PI()))/G10)*180/PI()	40
11				
12				
13				
14				
15				
16				
17				
18				
19				
20	Re1	Re2	δ_e	δi
21	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)	=(H3-SQRT((H3^2)-4*G3*I3))/(2*G3)	=ASIN((L21*SIN(140*PI()/180))/H21)*180/PI()	40
22	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)	=(H3-SQRT((H3^2)-4*G3*I3))/(2*G3)	=ASIN((L22*SIN(140*PI()/180))/H22)*180/PI()	40
23	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)	=(H3-SQRT((H3^2)-4*G3*I3))/(2*G3)	=ASIN((L23*SIN(140*PI()/180))/H23)*180/PI()	40
24	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)	=(H3-SQRT((H3^2)-4*G3*I3))/(2*G3)	=ASIN((L24*SIN(140*PI()/180))/H24)*180/PI()	40
25	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)	=(H3-SQRT((H3^2)-4*G3*I3))/(2*G3)	=ASIN((L25*SIN(140*PI()/180))/H25)*180/PI()	40
26				
27				
28				
29				
30	=(H3+SQRT((H3^2)-4*G3*J3))/(2*G3)		=ASIN((L30*SIN(140*PI()/180))/H30)*180/PI()	40
31	=(H3+SQRT((H3^2)-4*G3*J3))/(2*G3)		=ASIN((L31*SIN(140*PI()/180))/H31)*180/PI()	40
32				
33				
34				
35	x1	x	t	R2
36	42	=O36*COS(O36*PI()/180)	55	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)
37	42	=O37*COS(O37*PI()/180)	55	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)
38	42	=O38*COS(O38*PI()/180)	55	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)
39	42	=O39*COS(O39*PI()/180)	55	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)
40	42	=O40*COS(O40*PI()/180)	55	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)
41				
42				
43	42	=O43*COS(O43*PI()/180)	55	=(H3+SQRT((H3^2)-4*G3*J3))/(2*G3)
44	42	=O44*COS(O44*PI()/180)	55	=(H3+SQRT((H3^2)-4*G3*J3))/(2*G3)
45	42	=O45*COS(O45*PI()/180)	55	=(H3+SQRT((H3^2)-4*G3*J3))/(2*G3)
46	42	=O46*COS(O46*PI()/180)	55	=(H3+SQRT((H3^2)-4*G3*J3))/(2*G3)
47				
48				
49				
50	x1	x	t	R2
51				
52	42	=O52*COS(40*PI()/180)	55	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)
53	42	=O53*COS(40*PI()/180)	55	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)
54	42	=O54*COS(40*PI()/180)	55	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)
55	42	=O55*COS(40*PI()/180)	55	=(H3+SQRT((H3^2)-4*G3*I3))/(2*G3)
56				
57				
58				
59				
60				
61				

	P	Q	R	S
1				
2				
3				
4				
5	θ3	θ4		
6				
7	=ATAN((I7-H7)/(J7+K7))*180/PI()	=ATAN((I7-H7)/J7)*180/PI()		
8	=ATAN((I8-H8)/(J8+K8))*180/PI()	=ATAN((I8-H8)/J8)*180/PI()		
9	=ATAN((I9-H9)/(J9+K9))*180/PI()	=ATAN((I9-H9)/J9)*180/PI()		
10	=ATAN((I10-H10)/(J10+K10))*180/PI()	=ATAN((I10-H10)/J10)*180/PI()		
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35	θ1	θ2	θ3	θ4
36	=ASIN((O36*SIN(140*PI()/180)/J36)*180/PI()	40	=ATAN((L36/(M36+N36)))*180/PI()	=ATAN((L36/M36))*180/PI()
37	=ASIN((O37*SIN(140*PI()/180)/J37)*180/PI()	40	=ATAN((L37/(M37+N37)))*180/PI()	=ATAN((L37/M37))*180/PI()
38	=ASIN((O38*SIN(140*PI()/180)/J38)*180/PI()	40	=ATAN((L38/(M38+N38)))*180/PI()	=ATAN((L38/M38))*180/PI()
39	=ASIN((O39*SIN(140*PI()/180)/J39)*180/PI()	40	=ATAN((L39/(M39+N39)))*180/PI()	=ATAN((L39/M39))*180/PI()
40	=ASIN((O40*SIN(140*PI()/180)/J40)*180/PI()	40	=ATAN((L40/(M40+N40)))*180/PI()	=ATAN((L40/M40))*180/PI()
41				
42				
43	=ASIN((O43*SIN(140*PI()/180)/J43)*180/PI()	40	=ATAN((L43/(M43+N43)))*180/PI()	=ATAN((L43/M43))*180/PI()
44	=ASIN((O44*SIN(140*PI()/180)/J44)*180/PI()	40	=ATAN((L44/(M44+N44)))*180/PI()	=ATAN((L44/M44))*180/PI()
45	=ASIN((O45*SIN(140*PI()/180)/J45)*180/PI()	40	=ATAN((L45/(M45+N45)))*180/PI()	=ATAN((L45/M45))*180/PI()
46	=ASIN((O46*SIN(140*PI()/180)/J46)*180/PI()	40	=ATAN((L46/(M46+N46)))*180/PI()	=ATAN((L46/M46))*180/PI()
47				
48				
49				
50	θ1	θ2	θ3	θ4
51				
52	=ASIN((O52*SIN(140*PI()/180)/J52))*180/PI()	40	=ATAN((L52/(M52+N52)))*180/PI()	=ATAN((L52/M52))*180/PI()
53	=ASIN((O53*SIN(140*PI()/180)/J53))*180/PI()	40	=ATAN((L53/(M53+N53)))*180/PI()	=ATAN((L53/M53))*180/PI()
54	=ASIN((O54*SIN(140*PI()/180)/J54))*180/PI()	40	=ATAN((L54/(M54+N54)))*180/PI()	=ATAN((L54/M54))*180/PI()
55	=ASIN((O55*SIN(140*PI()/180)/J55))*180/PI()	40	=ATAN((L55/(M55+N55)))*180/PI()	=ATAN((L55/M55))*180/PI()
56				
57				
58				
59				
60				
61				

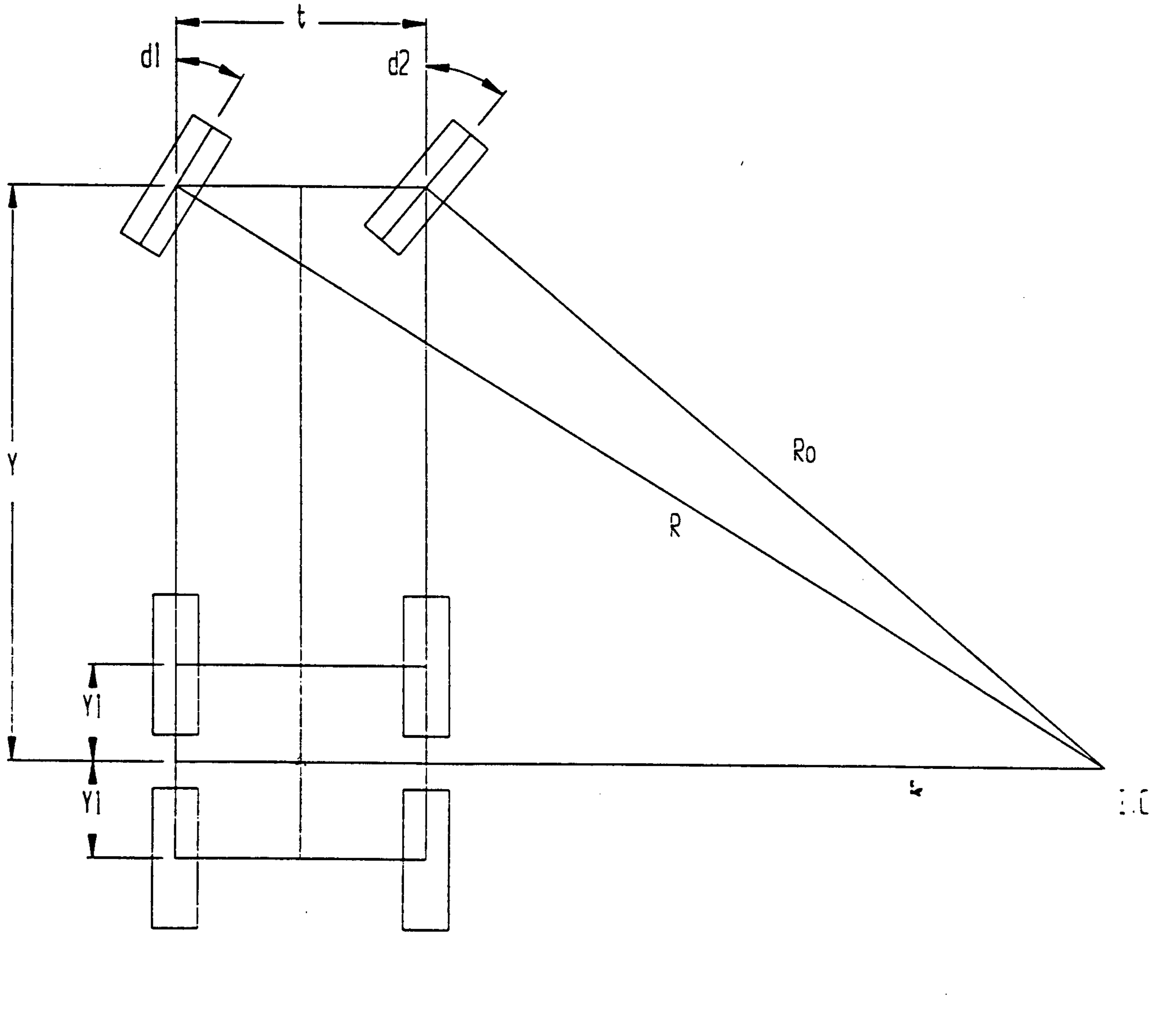
CASE 1: 4 WHEELED VEHICLE, REAR AXLE FIXED



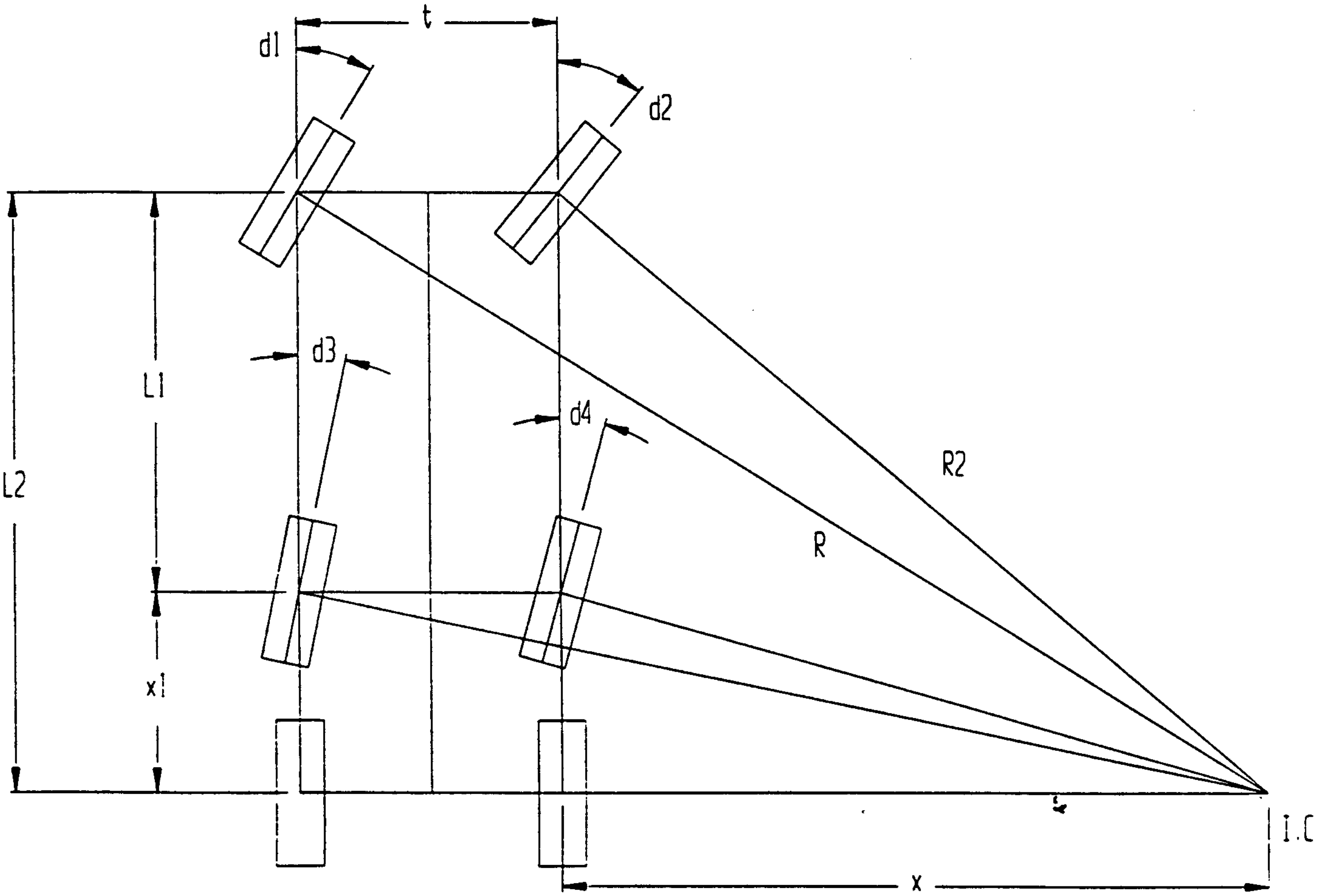
CASE 1: 4 WHEELED VEHICLE, BOTH AXLES STEER



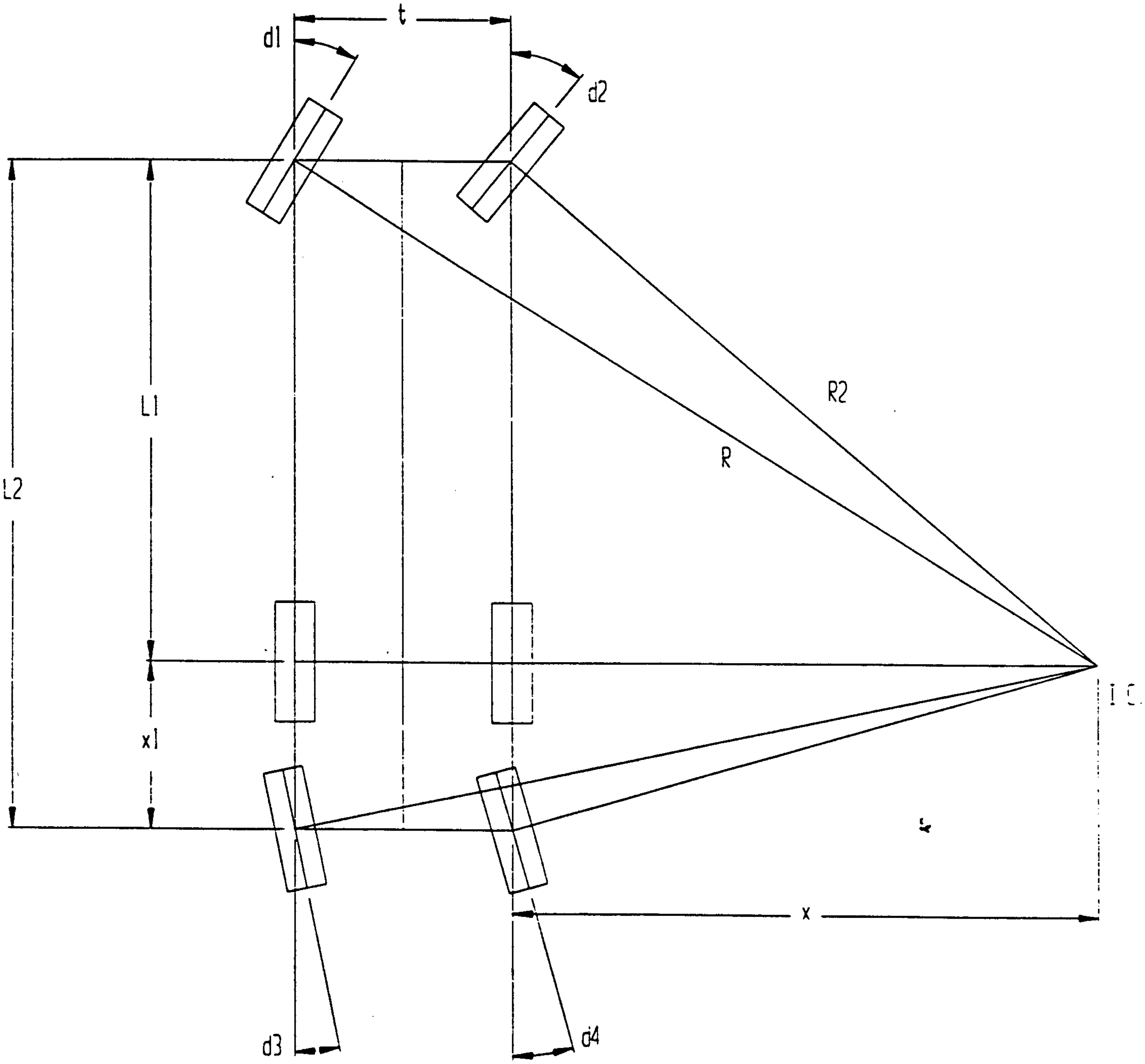
CASE 2: 6 WHEELED VEHICLE, REAR AXLES FIXED



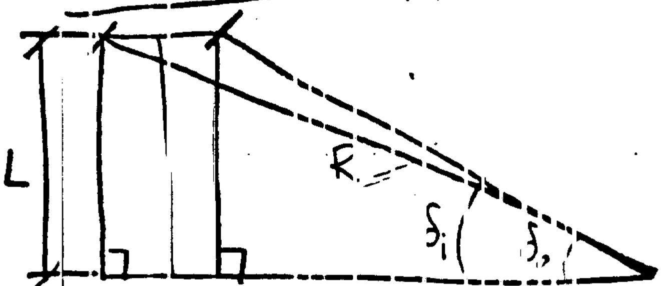
CASE 3: 6 WHEELED VEHICLE, REAR AXLE FIXED

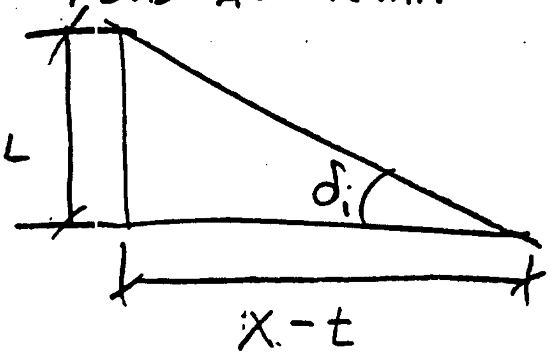


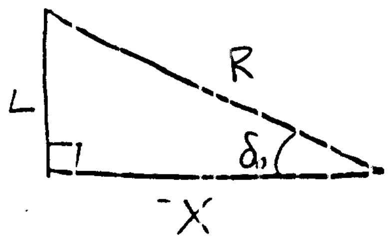
CASE 4: 6 WHEELED VEHICLE, CENTER AXLE FIXED



CASE I 4 WHEELED VEHICLE W/STD ACKERMAN







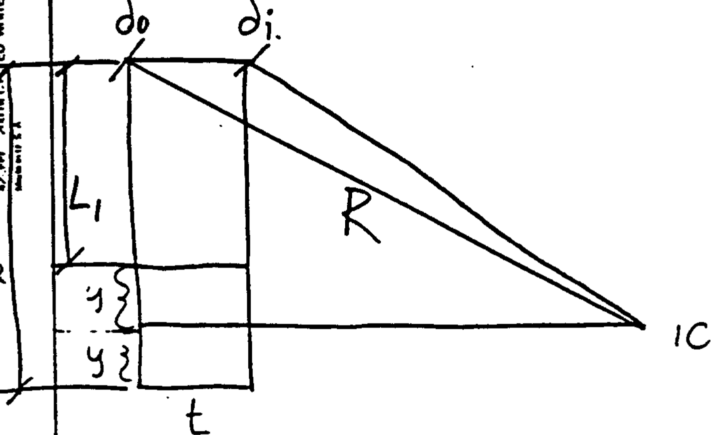
$$\boxed{\delta_o = \sin^{-1}\left(\frac{L}{R}\right)}$$

where R = turn radius
L = wheel base

$$X = \sqrt{R^2 - L^2}$$

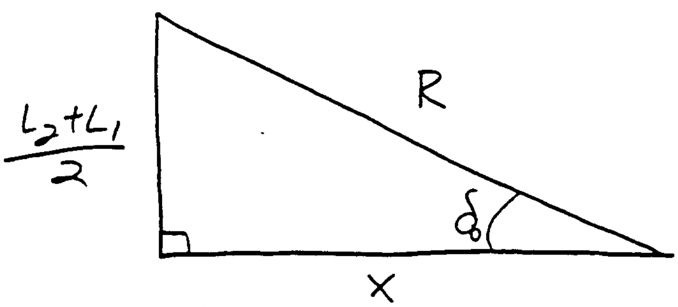
$$\delta_i = \tan^{-1}\left(\frac{L}{x-t}\right)$$

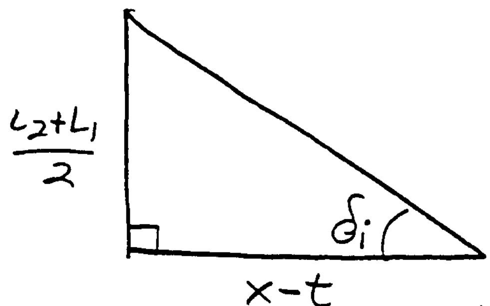
$$\boxed{\delta_i = \tan^{-1}\left[\frac{L}{\left(\sqrt{R^2 - L^2}\right) - t}\right]}$$



$R = 240{,}300$ TURNING R

$t = 55$ TRACK WIDTH



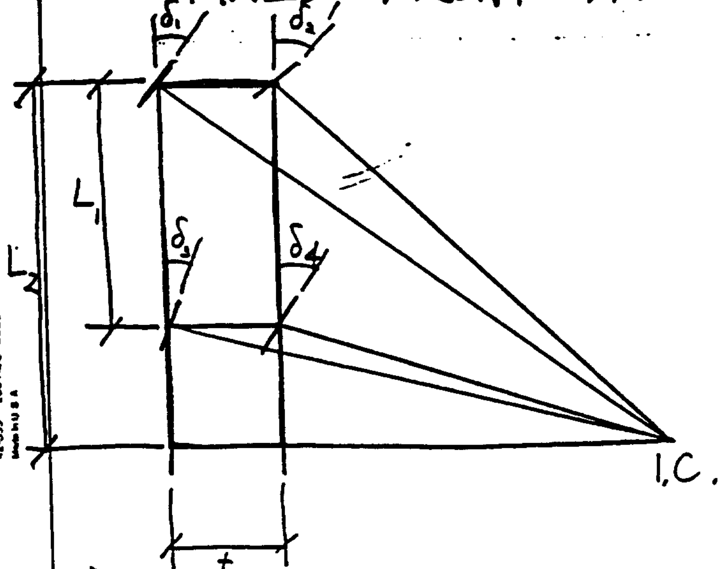


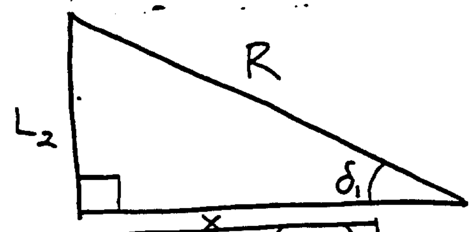
$$\boxed{\delta_o = \sin^{-1}\left(\frac{L_2+L_1}{2R}\right)}$$

$$\boxed{\delta_i = \tan^{-1}\left(\frac{L_2+L_1}{2(x-t)}\right)}$$

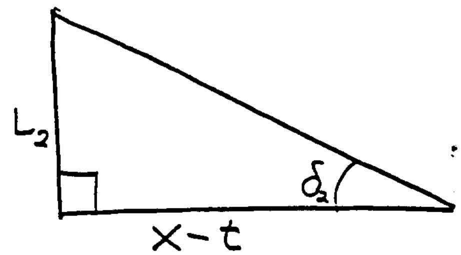
$$x = \sqrt{R^2 - \left(\frac{L_2+L_1}{2}\right)^2}$$

FIXED FRONT TWO STEER.





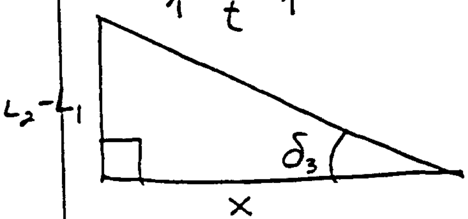
$$\boxed{\delta_1 = \sin^{-1}\left(\frac{L_2}{R}\right)}$$



$$x = \sqrt{R^2 - L_2^2}$$

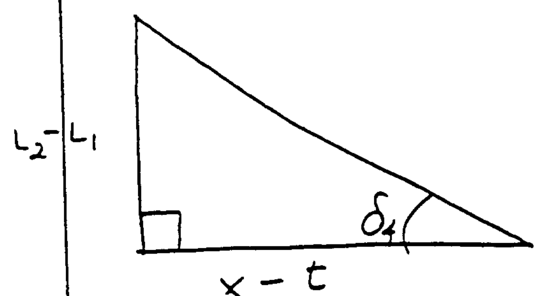
$$\delta_2 = \tan^{-1}\left(\frac{L_2}{x-t}\right)$$

$$\boxed{\delta_2 = \tan^{-1}\left[\frac{L_2}{\left(\sqrt{R^2-L_2^2}\right)-t}\right]}$$



$$\delta_3 = \tan^{-1}\left(\frac{L_2-L_1}{x}\right)$$

$$\boxed{\delta_3 = \tan^{-1}\left(\frac{L_2-L_1}{\sqrt{R^2-L_2^2}}\right)}$$

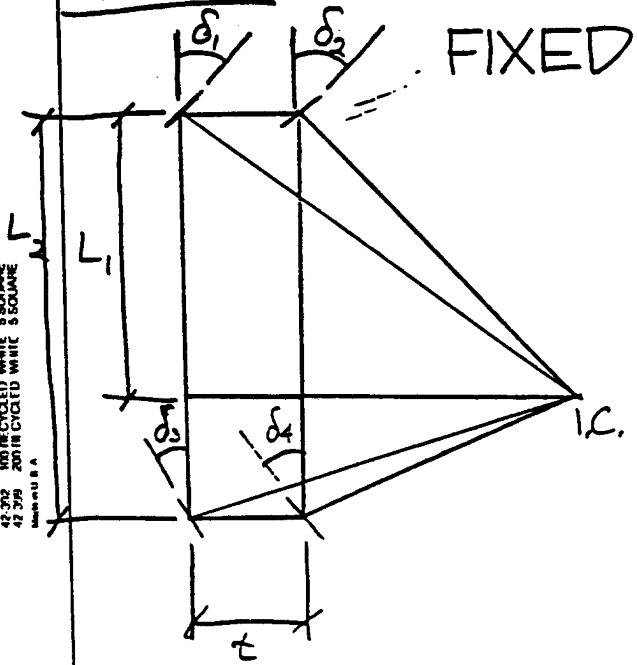


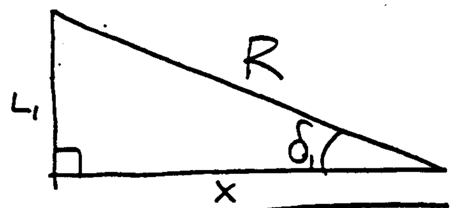
$$\delta_4 = \tan^{-1}\left(\frac{L_2-L_1}{x-t}\right)$$

$$\boxed{\delta_4 = \tan^{-1}\left(\frac{L_2-L_1}{\sqrt{R^2-L_2^2}-t}\right)}$$

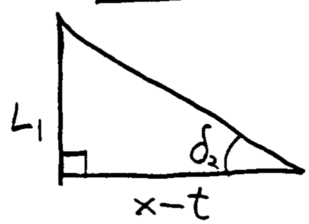
RSTV ACKERMAN

CASE 4: 6 WHEELED VEHICLE, CENTER AXLE FIXED



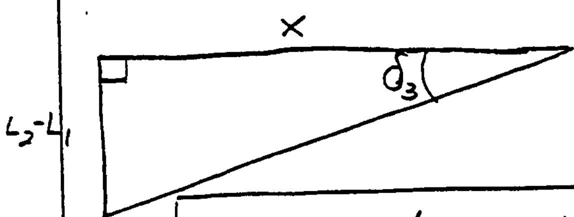


$$\boxed{\delta_1 = \sin^{-1}\left(\frac{L_1}{R}\right)}$$

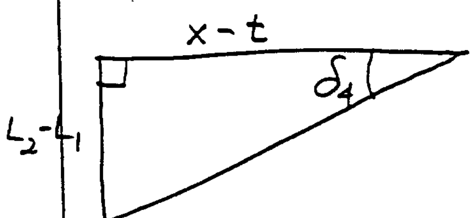


$$X = \sqrt{R^2 - L_1^2}$$

$$\boxed{\delta_2 = \tan^{-1}\left(\frac{L_1}{\sqrt{R^2-L_1^2} - t}\right)}$$



$$\boxed{\delta_3 = \tan^{-1}\left(\frac{L_2-L_1}{\sqrt{R^2-L_1^2}}\right)}$$

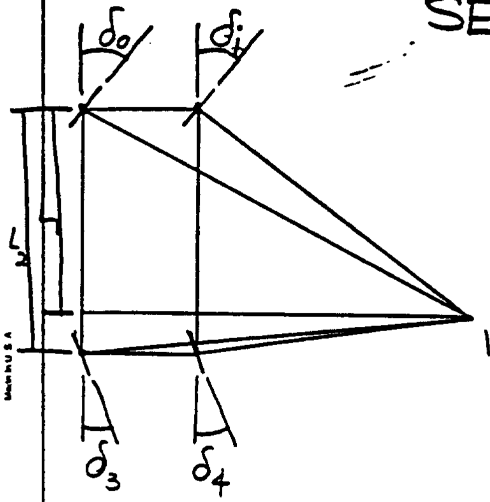


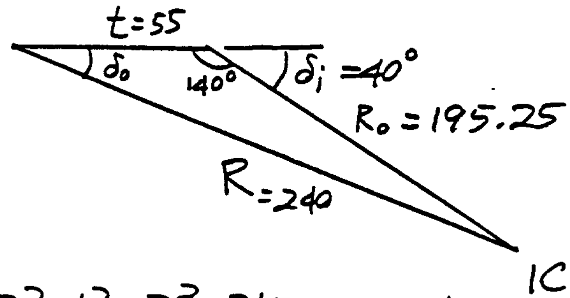
$$\boxed{\delta_4 = \tan^{-1}\left(\frac{L_2-L_1}{\sqrt{R^2-L_1^2} - t}\right)}$$

CASE 1: IF δ_o AND/OR $\delta_i > 40°$

LET R STAY THE SAME

SET $\boxed{\delta_i = 40°}$





$$x = \frac{-b \pm \sqrt{b^2-4ac}}{2a}$$

$$R^2 = t^2 + R_o^2 - 2tR_o \cos 140°$$

$$240^2 = 55^2 + R_o^2 - 2(55)R_o \cos 140°$$

$$57600 = 3025 + R_o^2 - 110\,R_o(-.766)$$

$$R_o^2 + 84.26R_o - 54575 = 0$$

$$R_o = \frac{-84.26 \pm \sqrt{84.26^2 - 4(1)(-54575)}}{2(1)}$$

$$R_o = \frac{-84.26 \pm 474.76}{2}$$

$$\boxed{R_o = 195.25},\ \cancel{-279.5}$$

$$R_o^2 - 2tR_o(\cos 140°) - R^2 + t^2 = 0$$

$$\frac{R_o}{\sin\delta_o} = \frac{R}{\sin 140°}$$

$$\frac{195.25}{\sin\delta_o} = \frac{240}{\sin 140°}$$

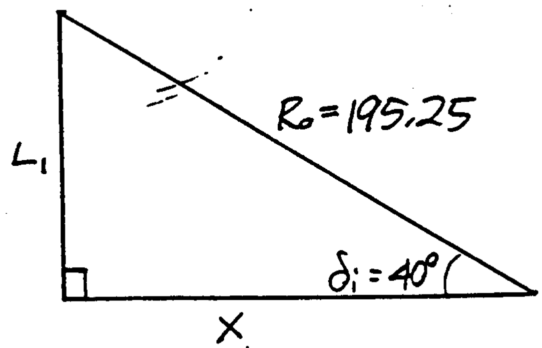
$$(195.25)\sin 140° = 240 \sin\delta_o$$

$$\delta_o = \sin^{-1}\left(\frac{(195.25)\sin 140°}{240}\right)$$

$$\boxed{\delta_o = 31.53°}$$

$$\boxed{\delta_o = \sin^{-1}\left(\frac{R_o \sin 140°}{R}\right)}$$

CASE 1: CONTINUED



$$\sin\delta_i = \frac{L_1}{R_o}$$

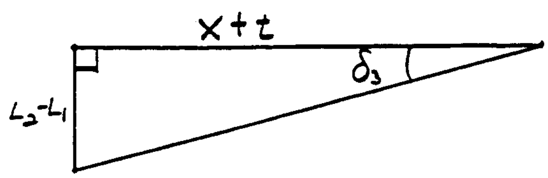
$$\boxed{L_1 = R_o \sin\delta_i}$$

$$L_1 = (195.25)\sin 40^\circ$$

$$\boxed{L_1 = 125.5}$$

$$x = \frac{L_1}{\tan\delta_i} = \frac{125.5}{\tan 40^\circ}$$

$$\boxed{X = 149.57}$$



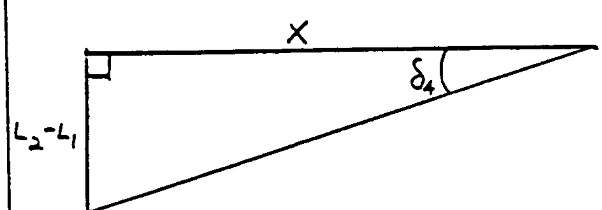
$$\tan\delta_3 = \frac{L_2 - L_1}{X + t}$$

$$\boxed{\delta_3 = \tan^{-1}\left(\frac{L_2 - L_1}{X + t}\right)}$$

LET $L_2 = 130$

$$\delta_3 = \tan^{-1}\left(\frac{130 - 125.5}{149.57 + 55}\right)$$

$$\boxed{\delta_3 = 1.26}$$



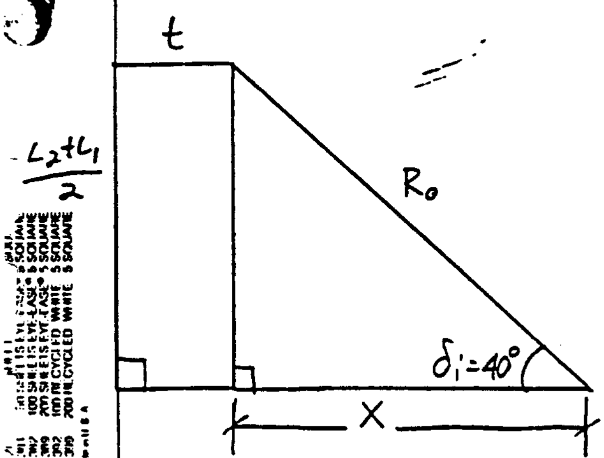
$$\tan\delta_4 = \frac{L_2 - L_1}{X}$$

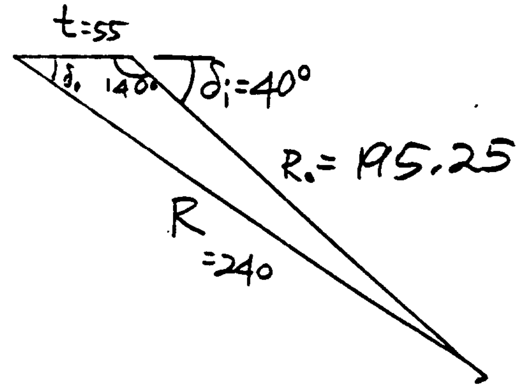
$$\boxed{\delta_4 = \tan^{-1}\left(\frac{L_2 - L_1}{X}\right)}$$

$$\delta_4 = \tan^{-1}\left(\frac{130 - 125.5}{149.57}\right)$$

$$\boxed{\delta_4 = 1.72}$$

CASE 2:





$$R^2 = t^2 + R_o^2 - 2tR_o \cos 140^\circ$$

$$240^2 = 55^2 + R_o^2 - 2(55)R_o \cos 140^\circ$$

$$\boxed{R_o = 195.25}$$

$$\sin 140^\circ = \frac{\frac{L_2+L_1}{2}}{R_o}$$

$$\boxed{2R_o \sin 140^\circ = L_2 + L_1}$$

$$L_2 + L_1 = 2(195.25)\sin 140$$

$$\boxed{L_2 + L_1 = 251}$$

$$\frac{R_o}{\sin \delta_o} = \frac{R}{\sin 140^\circ}$$

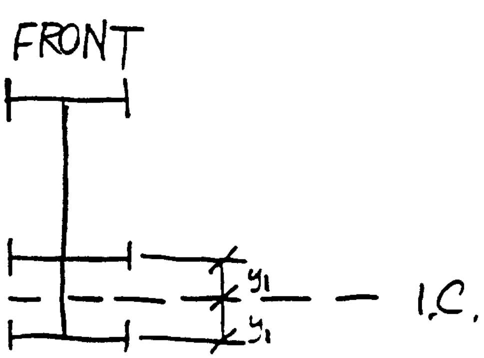
$$\boxed{\delta_o = \sin^{-1}\left(\frac{R_o \sin 140^\circ}{R}\right)}$$

$$\delta_o = \sin^{-1}\left(\frac{195.25 \sin 140^\circ}{240}\right) = \boxed{31.53^\circ}$$

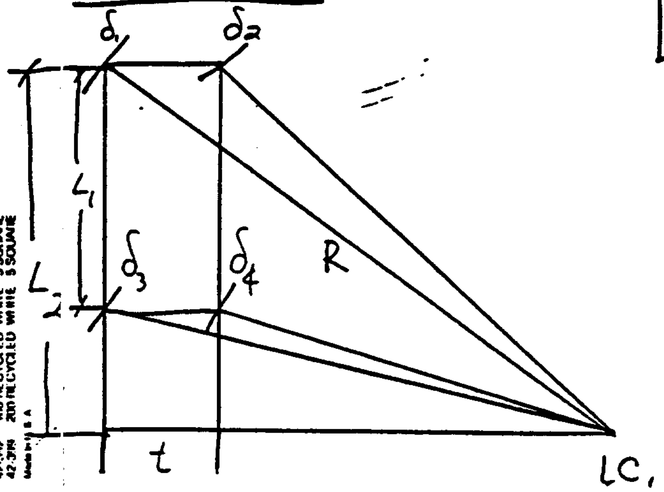
INSTANT CENTER (I.C.) LINE IS LOCATED $\frac{L_2+L_1}{2}$ (Y) FROM THE FRONT AXLE.

$$Y = \frac{251}{2} = \boxed{125.5}$$

I.C. LINE MUST BE ½ WAY BETWEEN AXLES 2 & 3.

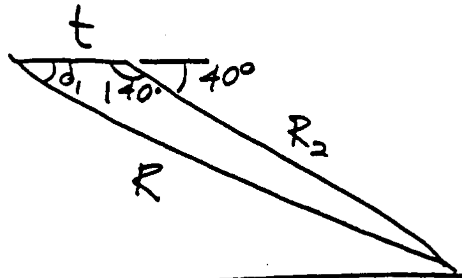


CASE 3:



$$\boxed{\delta_2 = 40^\circ}$$

$R = 240, 300$



$$\boxed{R^2 = t^2 + R_2^2 - 2tR_2\cos 140^\circ}$$

$$\boxed{R_2 = 195.25}$$

$$\frac{R}{\sin 140^\circ} = \frac{R_2}{\sin \delta_1}$$

$$\boxed{\delta_1 = \sin^{-1}\left(\frac{R_2 \sin 140^\circ}{R}\right)}$$

$$\delta_1 = \sin^{-1}\left(\frac{195.25 \sin 140^\circ}{240}\right)$$

$$\boxed{\delta_1 = 31.53^\circ}$$

$$\boxed{\delta_3 = \tan^{-1}\left(\frac{L_2 - L_1}{x + t}\right)}$$

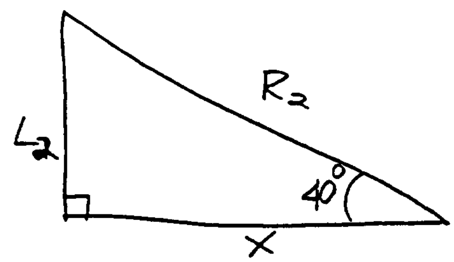
$$= \tan^{-1}\left(\frac{125.5 - (125.5 - 42)}{149.57 + 55}\right)$$

$$\boxed{\delta_3 = 11.602^\circ}$$

$$\boxed{\delta_4 = \tan^{-1}\left(\frac{L_2 - L_1}{x}\right)}$$

$$= \tan^{-1}\left(\frac{42}{149.57}\right)$$

$$\boxed{\delta_4 = 15.685^\circ}$$



$$\left(\frac{x}{R_2}\right) = \cos 40^\circ \qquad \sin 40^\circ = \frac{L_2}{R_2}$$

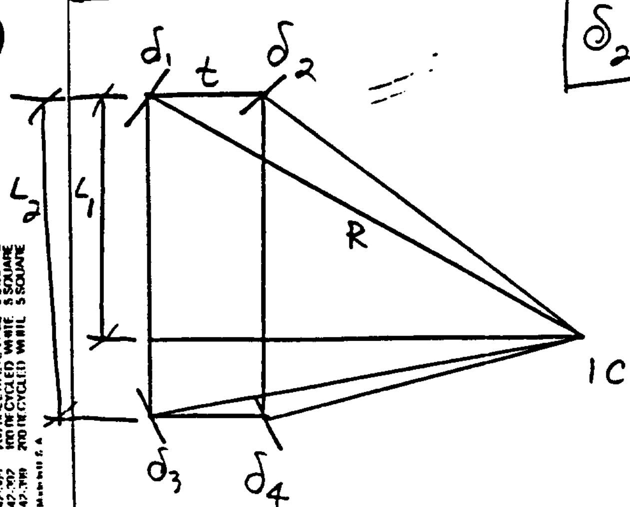
$$x = R_2 \cos 40^\circ \qquad L_2 = R_2 \sin 40^\circ$$

$$= 195.25 \cos 40^\circ \qquad = 195.25 \sin$$

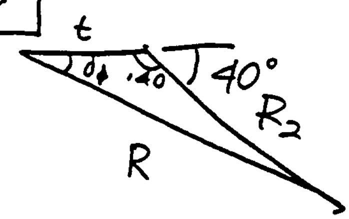
$$\boxed{x = 149.57} \qquad \boxed{L_2 = 125.5}$$

$L_1 = L_2 - x_1$ $\quad$ x_1 = axle spacing

CASE 4:



$\boxed{\delta_2 = 40^\circ}$



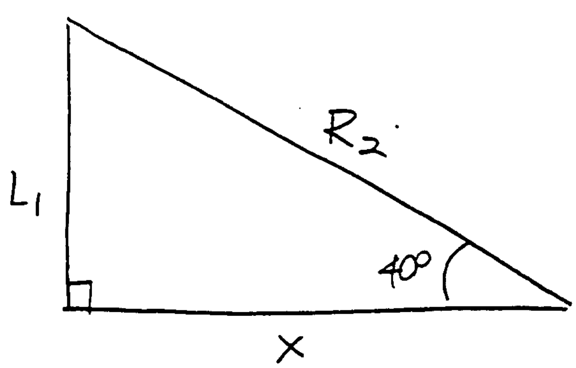
$$R^2 = t^2 + R_2^2 - 2tR_2\cos 140^\circ$$

$$\boxed{R_2 = 195.25}$$

$$\frac{R}{\sin 140^\circ} = \frac{R_2}{\sin\delta_1}$$

$$\boxed{\delta_1 = \sin^{-1}\left(\frac{R_2 \sin 140^\circ}{R}\right)}$$

$$\boxed{\delta_1 = 31.53}$$

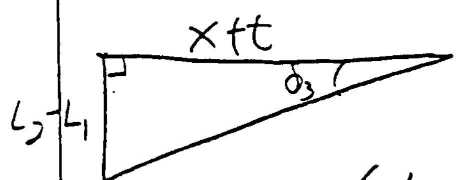


$$x = R_2 \cos 40^\circ$$

$$\boxed{x = 149.57}$$

$$L_1 = R_2 \sin 40^\circ$$

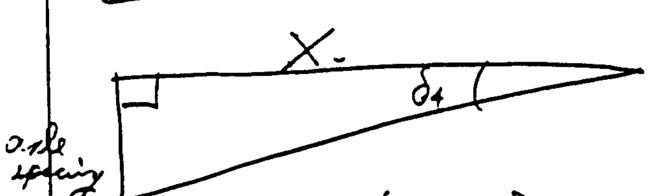
$$\boxed{L_1 = 125.503}$$



$$\delta_3 = \tan^{-1}\left(\frac{L_2 - L_1}{x+t}\right)$$

$$= \tan^{-1}\left(\frac{42}{149.57+55}\right) \Leftarrow L_2 - L_1 = \text{axle spacing}$$

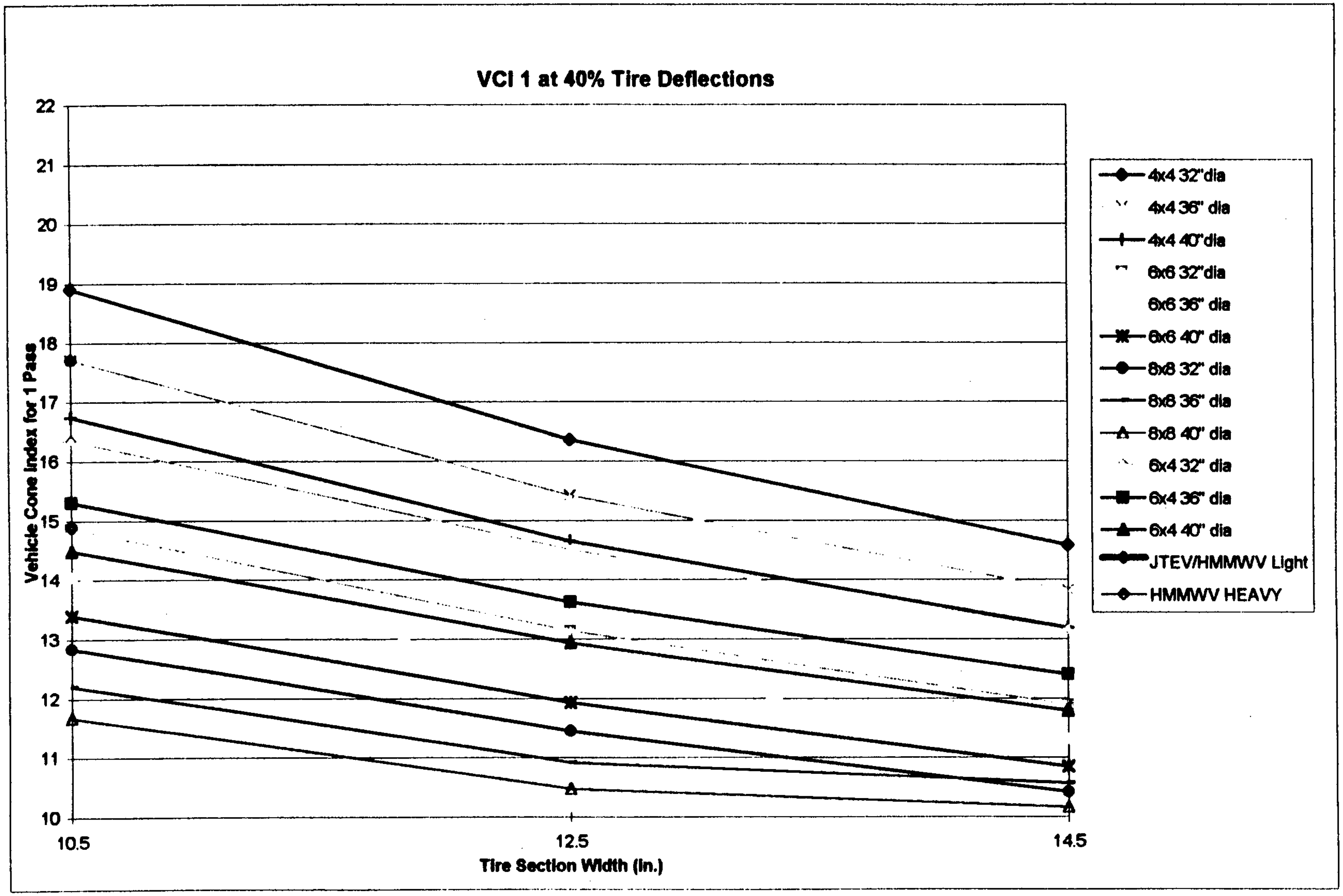
$$\boxed{\delta_3 = 11.6^\circ}$$



$$\delta_4 = \tan^{-1}\left(\frac{42}{x}\right)$$

$$\boxed{\delta_4 = 15.685^\circ}$$

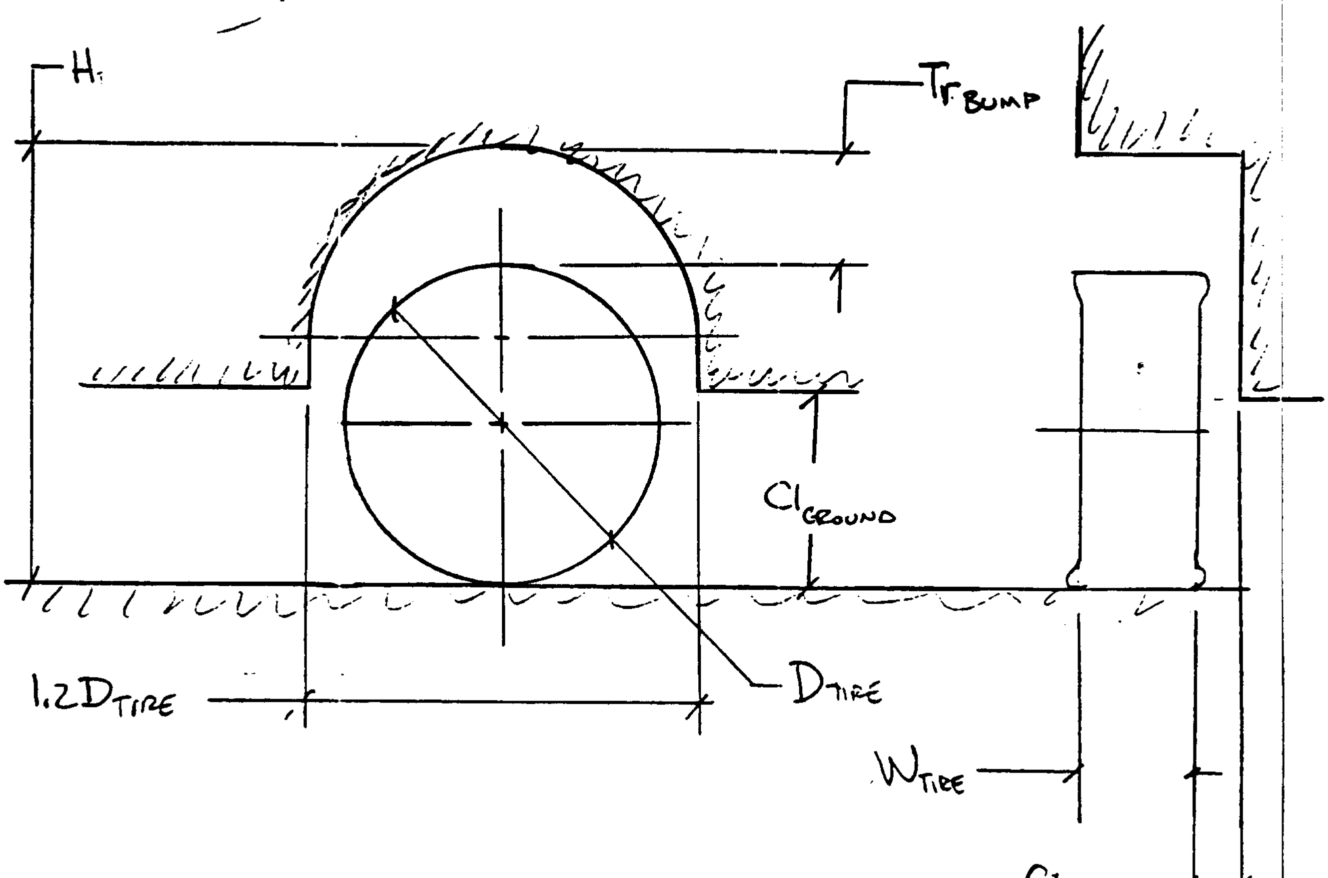
Appendix F Vehicle Cone Index Graph (representative)



VCI 1 at 40% Tire Deflections
Vehicle Cone Index for 1 Pass
22
21
20
19
18
17
16
15
14
13
12
11
10
10.5
12.5
14.5
Tire Section Width (in.)
4x4 32"dia
4x4 36" dia
4x4 40"dia
6x6 32"dia
6x6 36" dia
6x6 40" dia
8x8 32" dia
8x8 36" dia
8x8 40" dia
6x4 32" dia
6x4 36" dia
6x4 40" dia
JTEV/HMMWV Light
HMMWV HEAVY

Appendix G Wheel Displaced Volume and Suspension Study

WHEEL VOLUME STUDY 10/17/96

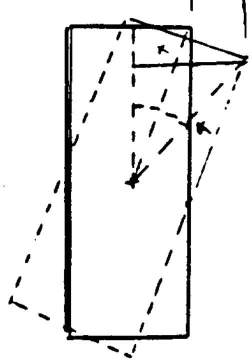


$H = D_{TIRE} + Tr_{BUMP}$

FOR STRAIGHT WHEELS

$$V_{DISPLACED} = \left[\frac{\pi}{2}\left(1.2\,\frac{D_{TIRE}}{2}\right)^2 + 1.2D_{TI}\left(H - \frac{1.2\,D_{TIRE}}{2} - CL_{GROUND}\right)\right] * \left(W_{TIRE} + Cl_{AXIAL}\right)$$

FOR TURNED WHEELS ADD



$$Cl_{TURN} = \sin\left(ANGLE_{TURN} + \tan^{-1}\frac{W_{TIRE}}{D_{TIRE}}\right)\left(\frac{\sqrt{W_{TIRE}^2 + D_{TIRE}^2}}{2}\right) - \frac{W_{TIRE}}{2}$$

EXAMPLE: (ϕ 40 TIRE, 40° TURN, 14.5" WIDE)

$$\sin\left(40° + \tan^{-1}\left(\frac{14.5}{40}\right)\right)\left(\frac{\sqrt{14.5^2 + 40^2}}{2}\right) - \frac{14.5}{2} = CL_{TURN}$$

.865

TOP VIEW

=

85

RSTV

Suspension Design Options

Beam Axle

Advantages

1. Low cost
2. Proven technology

Disadvantages

1. Large unsprung mass adversely affects handling
2. Roll center instability makes handling unpredictable
3. Heavy

Swing Arm

Advantages

1. Simple linkage
2. Provides high ground clearance

Disadvantages

1. Roll center location causes jacking effect, making vehicle prone to rollover
2) ZERO ROLL CAMBER GAIN

MacPherson Strut

Advantages

1. Simple linkage
2. Requires small space envelope

Disadvantages

1. Requires large diameter strut tube to resist bending loads
2. Roll center instablility
3. Not possible to optimize camber curve

Double A-arm

Advantages

1. Inherently strong
2. Wide range of possible suspension geometries

Disadvantages

1. Complex
2. Requires large space envelope

Radius Rods ?

Advantages

1. Simple parts
2. Inherently strong
3. Wide range of possible suspension geometries

Disadvantages

1. Complex
2. Has many parts
3. Requires large space envelope

Rigid Beam with Sliding Uprights

Advantages

1. Requires small space envelope

Disadvantages

1. Requires large linear bearings
2. Not possible to optimize suspension characteristics

'Super Strut' Variant of Mac Pherson Strut

Advantages

1. Requires small space envelope
2. Allows better geometry than conventional MacPherson strut

Disadvantages

1. Requires large diameter strut tube to resist bending loads
2. Requires some compromise of suspension characteristics
3. More complex than conventional MacPherson strut

Spring Configuration Options

Coil-over-shock absorber

Advantages

1. Simple

Disadvantages

1. Heavy
2. Limits packaging options
3. Requires either very long-travel springs and shocks or applying bending loads to suspenion arms
4. Difficult to implement variable ride height and spring rate

Air springs

Advantages

1. Easy to vary ride height
2. Difficult to vary spring rate

Disadvantages

1. Requires compressed air production and delivery system

Torsion bars

Advantages

1. Easy to vary ride height
2. Possible to implement variable spring rate

Disadvantages

1. Requires very long bars
2. Induces limited non-linearity in spring rate

Rocker-arms

Advantages

1. Allows positioning shocks in protected location
2. Well suited to use of torsion bars
3. Range of possible spring rate characteristics

Disadvantages

1. Large suspension links
2. Limited package options

Push rod actuated springs and shocks

Advantages

1. Allows packaging flexibility
2. Allows positioning shock absorbers in a protected area
3. Allows implementation of variable spriing rate and variable ride height
4. Well suited to use of structurally optimal linkages
5. Wide range of possible spring rate characteristics

Disadvantages

1. Added complexity

RST-V Swept Volume Calculations for Tire/Wheel Combinations

$V_{vehicle} := 312 \cdot ft^3$ Volume of vehicle from fit check

$D_{tire} := 40 \cdot in$ $W_{tire} := 14.5 \cdot in$ Tire dimensions $N_{tire} := 2$ Number of fixed tires

$Tr_{bump} := 12 \cdot in$ Jounce travel $H := D_{tire} + Tr_{bump}$ Height of inner fender

$Cl_{axial} := 4 \cdot in$ Clearances around wheels $Cl_{ground} := 16 \cdot in$ Ground Clearance

$$V_{displaced} := \left[\frac{\pi}{2} \cdot \left(1.2 \cdot \frac{D_{tire}}{2} \right)^2 + \left(1.2 \cdot D_{tire} \right) \cdot \left(H - \frac{1.2 \cdot D_{tire}}{2} - Cl_{ground} \right) \right] \cdot \left(W_{tire} + Cl_{axial} \right) \cdot N_{tire}$$

$V_{displaced} = 31.706 \cdot ft^3$ Volume displaced by fixed fender wells

$Angle_{turn1} := 40 \cdot deg$ $\quad N_{turn1} := 2$ Turn angle and number of turned wheels

$$Cl_{turn1} := \sin\left(Angle_{turn1} + \operatorname{atan}\left(\frac{W_{tire}}{D_{tire}}\right)\right) \cdot \left[\frac{\left(W_{tire}^2 + D_{tire}^2\right)^{.5}}{2}\right] - \frac{W_{tire}}{2}$$

$Cl_{turn1} = 11.16 \cdot in$ Extra clearance required for turning wheels

$$Vt_{displaced1} := \left[\frac{\pi}{2} \cdot \left(1.2 \cdot \frac{D_{tire}}{2}\right)^2 + \left(1.2 \cdot D_{tire}\right) \cdot \left(H - \frac{1.2 \cdot D_{tire}}{2} - Cl_{ground}\right)\right] \cdot \left(W_{tire} + Cl_{axial} + Cl_{turn1}\right) \cdot N_{turn1}$$

$Vt_{displaced1} = 50.832 \cdot ft^3$ Volume displaced by turned wheels fender wheels

$Angle_{turn2} := 32 \cdot deg$ $\quad N_{turn2} := 2$ Turn angle and number of turned wheels

$$Cl_{turn2} := \sin\left(Angle_{turn2} + \operatorname{atan}\left(\frac{W_{tire}}{D_{tire}}\right)\right) \cdot \frac{\left(W_{tire}^2 + D_{tire}^2\right)^{.5}}{2} - \frac{W_{tire}}{2}$$

$Cl_{turn2} = 9.497 \cdot in$ Extra clearance required for turning wheels

$$Vt_{displaced2} := \left[\frac{\pi}{2} \cdot \left(1.2 \cdot \frac{D_{tire}}{2}\right)^2 + \left(1.2 \cdot D_{tire}\right) \cdot \left(H - \frac{1.2 \cdot D_{tire}}{2} - Cl_{ground}\right)\right] \cdot \left(W_{tire} + Cl_{axial} + Cl_{turn2}\right) \cdot N_{turn2}$$

$Vt_{displaced2} = 47.983 \cdot ft^3$ Volume displaced by turned wheels fender wheels

$Angle_{turn3} := 12 \cdot deg \quad N_{turn3} := 2$ Turn angle and number of turned wheels

$$Cl_{turn3} := \sin\left(Angle_{turn3} + \operatorname{atan}\left(\frac{W_{tire}}{D_{tire}}\right)\right) \cdot \frac{\left(W_{tire}^{2} + D_{tire}^{2}\right)^{.5}}{2} - \frac{W_{tire}}{2}$$

$Cl_{turn3} = 4 \cdot in$ Extra clearance required for turning wheels

$$Vt_{displaced3} := \left[\frac{\pi}{2} \cdot \left(1.2 \cdot \frac{D_{tire}}{2}\right)^{2} + \left(1.2 \cdot D_{tire}\right) \cdot \left(H - \frac{1.2 \cdot D_{tire}}{2} - Cl_{ground}\right)\right] \cdot \left(W_{tire} + Cl_{axial} + Cl_{turn3}\right) \cdot N_{turn3}$$

$Vt_{displaced3} = 38.562 \cdot ft^{3}$ Volume displaced by turned wheels fender wheels

$$Vtot_{displaced} := V_{displaced} + Vt_{displaced1} + Vt_{displaced2} + Vt_{displaced3}$$

$Vtot_{displaced} = 169.1 \cdot ft^{3}$ Total volume displaced by fender wells

$V_{percent} := \frac{Vtot_{displaced}}{V_{vehicle}} \cdot 100 \qquad V_{percent} = 54.2$ Percentage of vehicle volume dedicated to fender wells

Appendix H Drivetrain Configuration Considerations

RSTV

Prime Mover Options

Diesel Internal Combustion Engine

Advantages

1. Low cost
2. Proven technology
3. Uses exiting service and training infrastructure
4. Relatively low thermal signature
5. Can be push or crank-started w/o electric power
6. Compatible with direct drive configuration

Disadvantages

1. Low power density (270 -340 kW/m^3)
2. Low specific power (.40-.49 kW/kg)
3. Large optical signature exhaust
4. High cooling requirements in stationary or low-speed application

Gas Turbine

Advantages

1. High power density (670-1180 kW/ m^3)
2. High specific power (.66-2.17 kW/kg)
3. Relatively constant thermal efficiency at varying power levels
4. Low optical signature exhaust
5. Excellent compatibility with series hybrid drives due to excellent constant-speed performance
6. Capable of full power output while vehicle is stationary
7. Low maintenence
8. Excellent interface with smaller, high rpm generator
9. Adaptable to multiple engines, providing redundancy
10. Can implement multi-fuel capability, including jet fuel and gasoline

Issues requiring further investigation:

1. Service interval
2. Reliability

Disadvantages

1. High cost
2. Relatively intolerant of neglect and abuse
3. Requires additional training and service infrastructure (but can be combined with helicopter service)
4. Poor compatibility with direct drive configurations
5. Relatively new technology
6. Large thermal signature exhaust requires mitigation

Drive Configuration Options

Hydrodynamic Drive

Hydrodynamic direct drive is a mechanical power transmission and drive system consisting of a hydrodynamic coupling (a torque converter) driving a multi-speed automatic transmission. The output shaft of the transmission is coupled to the wheels via conventional mechanical means. Due to the varying speed required, this type of drive is more suited to use of an internal combustion prime mover, and poorly suited to use of a gas turbine.

Advantages
1. Conventional, proven technology
2. Alternative start capability easy to implement

Disadvantages
1. Limits options for drivetrain packaging
2. Requires auxiliary power source to drive sensor suite

Hydrostatic Drive

Hydrostatic drive consists of a hydraulic pump driven by the prime mover, coupled to the drive wheels via a hydraulic system. This type of drive can utilize either type of prime mover.

Advantages
1. Flexible drivetrain packaging
2. Drive components are relatively compact

Disadvantages
1. Relatively complex system
2. Requires auxiliary power source to drive sensor suite
3. Cost

Variants of the hydrostatic drive:
single drive motor

Advantages
1. Simplicity

Disadvantages
1. Pointless
2. Limits packaging options
3. Limited 'limp-home' capably

two drive motors, one front and one rear

Advantages
1. Redundant drives allow mobility in case of failure of one drive
2. Potential packaging advantage in rear of 6x6 configuration

Disadvantages
1. Added complexity
2. Requires different motors if front and rear axles are not loaded approximately equally
3. Requires coupling rear axles if used in 6x6 configuration

one drive motor per axle

Advantages

1. Modular drive package
2. Redundant drives allow mobility in case of failure of one drive
3. Lends itself to traction control

Disadvantages

1. Added complexity

Parallel Hybrid Hydrodynamic Electric Drive

Parallel hybrid electric drive consists of a hydrodynamic drive system augmented as required by one or more electric motors. When not producing drive power, the motor or motors are used to generate electricity, which is stored in batteries on the vehicle. Due to the varying speed required, this type of drive is more suited to use of an internal combustion prime mover.

Advantages

1. Integral electric power generation capability to power sensor suite
2. Allows limited mobility in the event of failure of the prime mover
3. Easily implemented push-start capability
4. Allows use of a smaller prime mover for a given dash capability or grade abililty
5. Uses one piece of hardware for both motor and generator

Disadvantages

1. Limited drivetrain packaging options
2. New Technology
3. Cost
4. Some complexity to implement stationary power generation

Variants of the parallel hybrid hydrodynamic electric drive:

single drive motor

Advantages

1. Simplicity

Disadvantages

1. Limits packaging options
2. Limited 'limp-home' capably

two drive motors, one front and one rear

Advantages

1. Redundant drives allow mobility in case of failure of one drive
2. Potential packaging advantage in rear of 6x6 configuration

Disadvantages

1. Added complexity
2. Difficult to implement stationary power generation
3. Requires different motors and controllers if front and rear axles are not loaded approximately equally
4. Requires coupling rear axles if used in 6x6 configuration

one drive motor per axle

Advantages

1. Modular drive package
2. Redundant drives allow mobility in case of failure of one drive
3. Well suited to traction control

Disadvantages

1. Added complexity
2. More difficult to implement stationary power generation

Parallel Hybrid Hydrostatic Electric Drive

A parallel hybrid electric drive consists of a hydrostatic drive system augmented as required by an electric motor. When not producing drive power, the electric motor is used to generate electricity, which is stored in batteries on the vehicle.

Advantages

1. Integral electric power generation capability to power sensor suite
2. Allows limited mobility in the event of failure of the prime mover
3. Easily implemented push-start capability
4. Allows use of a smaller prime mover for a given dash capabilityor grade abililty
5. Uses one piece of hardware for both power augmentation and generator
6. Compact drive system allows packaging flexibility

Disadvantages

1. New Technology
2. Cost
3. Complexity

Variants of the parallel hybrid hydrodynamic electric drive:

single drive motor

Advantages

1. Simplicity

Disadvantages

1. Limits packaging options
2. Limited 'limp-home' capably

two drive motors, one front and one rear

Advantages

1. Redundant drives allow mobility in case of failure of one drive
2. Potential packaging advantage in rear of 6x6 configuration

Disadvantages

1. Added complexity
2. Requires different motors and controllers if front and rear axles are not loaded approximately equally
3. Requires coupling rear axles if used in 6x6 configuration

one drive motor per axle

Advantages

1. Modular drive package
2. Redundant drives allow mobility in case of failure of one drive
3. Well suited to traction control

Disadvantages

1. Added complexity

Series Hybrid Electric Drive

Series hybrid electric drive describes an electric propulsion system, an on-board generator set, and a battery pack. The propulsion system can draw power from the batteries, or in high demand situations, from the generator and the batteries simultaneously. The generator set, when running, runs at constant speed and varying load. A gas turbine prime mover is ideal for this type of application.

Advantages

1. Allows use of a smaller prime mover for a given dash capability
2. Constant prime mover speed increases efficiency
3. Integral, very direct stationary electric power generation capability to power sensor suite

Disadvantages

1. Complex system
2. Cost
3. New technology
4. Difficult to implement alternative start capability
5. Requres separate devices for power generation and drive functions

Variants of the series hybrid electric drive

single drive motor

Advantages

1. Simplicity

Disadvantages

1. Requires large motor
2. Limits packaging options
3. Limited 'limp-home' capably

two drive motors, one front and one rear

Advantages

1. Redundant drives allow mobility in case of failure of one drive
2. Potential packaging advantage in rear of 6x6 configuration

Disadvantages

1. Added complexity
2. Requires different motors and controllers if front and rear axles are not loaded approximately equally
3. Requires coupling rear axles if used in 6x6 configuration

one drive motor per axle

Advantages

1. Modular drive package
2. Redundant drives allow mobility in case of failure of one drive
3. Well suited to traction control

Disadvantages

1. Added complexity

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Alternative Start Systems

Air start

Advantages
1. Compact
2. Simple

Disadvantages
1. Requires additional system with no other function
2. Limited number of start attempts
3. Does not recharge

Push start

Advantages
1. Compact
2. Simple
3. Can allow starting of vehicle with all on-board energy storage depleted

Disadvantages
1. Requires second vehicle (not necessarily NATO spec) to push with, or fortutious locaton of a grade
2. Added mechanical complexity
3. Some loss of packaging flexibility

Hand Crank Start

Advantages
1. Compact
2. Simple
3. Can allow starting of vehicle with all on-board energy storage depleted

Disadvantages
1. Physically dfficult to do in the field
2. Added mechanical complexity